Type 2 diabetes and the double burden of malnutrition in rural south India: A mixed-methods examination of a public health crisis

by

Matthew Little

A Thesis
Presented to
The University of Guelph

In partial fulfillment of requirements
for the degree of
Doctor of Philosophy
in
Population Medicine and International Development Studies

Guelph, Ontario, Canada

ABSTRACT

TYPE 2 DIABETES AND THE DOUBLE BURDEN OF MALNUTRITION IN RURAL SOUTH INDIA: A MIXED-METHODS EXAMINATION OF A PUBLIC HEALTH CRISIS

Matthew Little

Advisors:
Dr. Cate Dewey
Dr. Sally Humphries

India is experiencing a nutrition transition characterized by shifting diets and physical activity patterns that are driving increased prevalence of obesity, type 2 diabetes, and the double burden of malnutrition (defined as co-occurring under- and over-nutrition). The objective of this research was to describe and determine factors associated with these phenomena in rural Tamil Nadu, India using a mixed methods (qualitative and quantitative) study design. In-depth interviews (n=61+54) and focus groups (n=8) assessed perceptions of diabetes, nutrition, and the local food environment. Randomly selected adults (n=753) participated in a socio-demographic survey, food frequency questionnaire, and bio-metric measurements (waist/hip circumference ratio [WHR], body mass index [BMI], blood hemoglobin, and oral glucose tolerance test). Age- and sex-standardized prevalences of health outcomes were: overweight, 34%; pre-diabetes, 9.5%; type 2 diabetes, 10.8%; underweight, 23%; and anemia, 47%. Prevalence of co-morbid anemia plus overweight was 22.6% in women and 12.0% in men, while prevalence of co-morbid anemia plus diabetes was 5.6% of men and women. Multivariable linear and logistic regressions were used to identify factors associated with health outcomes at $p<0.05$. Factors [odds ratios] associated with obesity included physical activity [0.8], wealth index [1.1], high caste [4.6], rurality index [0.4], and tobacco use [0.2]. Factors [ORs] associated with diabetes included physical activity [0.8], BMI [1.9], WHR [1.6], high caste [2.4], rurality index [0.8], and tobacco use [2.8]. Factors [ORs] associated with co-morbid anemia and overweight included female sex [2.3], rurality index [0.7], high caste [0.7], wealth index [1.1], livestock ownership [0.5], and meat intake [0.8]. Factors [ORs] associated with co-morbid anemia and diabetes included age [1.1], rurality index [0.8], family history of diabetes [4.9], and BMI [2.1]. Local explanatory models of diabetes cited “poor diet”, “tension”, and “tradition” (family history). Illness narratives described “fear” and “loss of control” upon diagnosis with diabetes. Food environment characteristics affecting food choices and consumption included individual factors (age, gender), socio-economic factors (wealth, caste, religion), access to government entitlements, occupation, and media exposure. Results shed light on public health issues in rural India and carry implications for policy, practice, and future research.

ACKNOWLEDGEMENTS

As my PhD studies come to a close, I am grateful for the support and guidance of many individuals. First and foremost, I am forever indebted to my PhD committee members for their willingness to provide supervisory, methodological, logistical, and financial support. Thank you to my co-supervisor Dr. Sally Humphries, who agreed to supervise an undergraduate independent study in Guatemala all those years ago, and who introduced me to the joys and challenges of international development and global health research. Without Dr. Humphries' support, supervision, and encouragement, I would never have entered a PhD program at the University of Guelph. Sally, your strong commitment to community engagement, humility, and integrity shaped and bettered my research, and I will carry these principles with me into my research career. Thank you as well to Dr. Cate Dewey, my co-supervisor in Population Medicine, whose empathy, insight, and unending curiosity constantly reminded me of the value of global health research and permitted me to overcome numerous challenges. Cate, I am so grateful to have you as a mentor, and for all your patient support and guidance. I am amazed and impressed at your dedication to developing meaningful relationships with all your students. Most importantly, thank you Sally and Cate for being good friends throughout the research and writing process, and for sharing many laughs along the way.

Thanks as well to Dr. Kirit Patel, who was an excellent and empathetic leader of the overarching project, "Revalorizing small millets in rainfed regions of south Asia" (RESMISA). Kirit, your knowledge of the Indian context, your insights into the complexities of conducting research in India, and your persistent enthusiasm were invaluable to the success of my research. I know that my year spent conducting research in rural Tamil Nadu would never have been possible without your support, strong community relationships, and constant encouragement.

RESMISA was a large and complex international development research project, and I am grateful to the investigators and partner organizations for their willingness to support my research objectives and assist with logistics and methods. Thank you to the Development of Humane Action (DHAN) Foundation for acting as a partner organization. Specifically, M. Karthikeyan in the Krishnagiri office and V. Vediyappan and M. Suresh in the Anchetty field office provided extensive support, from hiring research assistants to finding housing. Thank you as well to Ms. Sudha Vasudevan, Dr. Mohan, and their team of researchers at the Madras Diabetes Research Foundation for permitting me to use their validated food frequency questionnaire.

I owe many thanks to the research assistants, without whom I would never have been able to buy a motorcycle, let alone seek clearances from local authorities, conduct interviews, obtain and process blood samples, and overcome the myriad of daily challenges that arise during fieldwork. T. Madhe Gowda, I may have recently missed your wedding, but I hope to visit your new family someday. Your support, assistance, and most of all, your friendship, were crucial to our success. You were more a partner than an assistant, and I truly hope that you achieve all the crazy dreams you have. N. Kodhai Priya and Priscilla Dhanapal, I still barely believe you accepted jobs as nutrition researchers with a strange Canadian you had never met, but I will be forever grateful for your enthusiasm, proficiency, and empathy. Dr. Vikas Kumar, I am sorry we never visited Himachal Pradesh, but I am glad we lived together in Anchetty and you taught me how to cook butter chicken “just like mom makes”. The entire research team appreciated your wisdom, professionalism, and constant comic relief. Finally, R. Rajesh, you stepped in as a nurse when you were most needed and saved the project, and for that I will be forever grateful. You also drove me to Krishnagiri multiple times, took care of me when I was ill, and gave me a tetanus shot when I walked into a piece of rusty sheet metal. Your support, assistance, and friendship will always be remembered. Finally, thank you to many of the friends in Anchetty that made me feel welcome, including Vahijahn, Shankara, Suresh, and Vasanth. Special thanks are owed to Gopi, who made the best chai in Tamil Nadu and was always willing to beat me in a game of chess.

Most importantly, thank you to all of the fascinating individuals participated in the qualitative and quantitative studies. Many participants will be remembered for their charisma, generosity, and willingness to share their fascinating stories.

I am very grateful for the numerous institutions and organizations that provided financial support for this work. I was honored to receive a Vanier Canada Graduate Scholarship and a Michael Smith Foreign Study Supplement through the Canadian Institutes for Health Research (CIHR), a Doctoral Research Award through the International Development Research Centre, and an Ontario Veterinary College Incoming Student Scholarship. I received additional financial support by RESMISA funds through the Canadian International Food Security Research Fund, provided by IDRC and the Department of Foreign Affairs, Trade, and Development (DFATD, formerly the Canadian International Development Agency and now Global Affairs Canada).

Many thanks are owed to faculty, staff, and peers at the University of Guelph. Dr. Sherilee Harper, you have been a mentor and an inspiration. Dr. Craig Johnston, Dr. David Pearl, and Dr. Jason Coe, many thanks for providing support and encouragement at various stages of my PhD work. Sally Maclachlan and Linda Kraemer, thank you for all your assistance in navigating the logistical and financial challenges of work in India, and I forgive you for taking three years to realize that Warren Dodd (now Dr. Dodd) and I were, in fact, different

people. And Warren, I owe you a major debt of gratitude for your companionship throughout our PhD studies, especially during our first trip to Anchetty. Congratulations on your impressive dissertation - I am awestruck by your dedication to community engagement and global health research, and I look forward to a lifelong friendship.

I have a strong community of friends and family who have been sources of inspiration and reprieve throughout this journey. Thanks are owed to my parents, Bob and Betsy, who offered endless encouragement over the past five years. Special thanks as well to my brother Kevin and friends Sean Gallagher and Matt Smider, who were always up for an adventure when I needed a break. And finally, thank you Holly, you taught me the value of finding balance in life, and continually inspire me to seize the day, no matter where we wake up.

STATEMENT OF WORK

STUDY DESIGN:

The research presented in this dissertation was a component of a large, interdisciplinary international development research project titled “Revalorizing Small Millets in the Rainfed Regions of South Asia” (RESMISA). This project received funding through the Canadian International Food Security Research Fund (CIFSRF), administered by the International Development Research Centre (IDRC) and the Department of Foreign Affairs, Trade, and Development (DFATD, formerly the Canadian International Development Agency and now Global Affairs Canada). Co-supervisor Dr. Sally Humphries was the gender specialist on this project. Supervisory committee member Dr. Kirit Patel was the principal investigator. RESMISA conducted research activities in eight different sites, one of which was Anchetty, where I conducted all research activities for my PhD.

I designed all studies included in this dissertation under the auspices of RESMISA, and with input from committee members and collaborators with the Development for Humane Action (DHAN) Foundation. Qualitative and quantitative tools were developed or adapted with assistance from Drs. Sally Humphries, Cate Dewey, Kirit Patel, and Warren Dodd. Some quantitative methods were adapted from existing validated tools. Specifically, the Global Physical Activity Questionnaire (GPAQ) was developed by the World Health Organization (WHO 2011), however we selected visual prompts relevant to the local context (i.e. I photographed and printed local images depicting ‘easy’, ‘moderate’, and ‘vigorous’ physical activity). The rurality index was adapted from the tool developed for use in rural United States by Weinert and Boik (1995). The food frequency questionnaire (FFQ) and accompanying Food Atlas and EpiNu™ software program were developed by the Madras Diabetes Research

Foundation (MDRF) and adapted slightly for use in a rural region by including locally available foods and seasonal fruits. MDRF trained four research assistants (T. Madhe Gowda, Dr. Vikas Kumar, N. Kodhai Priya, and Priscilla Dhanapal) and myself to properly administer the FFQ during a three-day workshop in Chennai, Tamil Nadu, in early December 2013. I provided monetary royalties to MDRF for use of the FFQ, Food Atlases, and EpiNu™, as well as for the training workshop. I brokered this agreement with Ms. Sudha Vasudevan, Head of the Foods, Nutrition, and Dietetics Department at Dr. Mohan's Diabetes Specialties Centre and MDRF.

During the first year of my PhD studies, I received a research stipend through the RESMISA project. Following this, I applied for and secured funding for my research activities from the Canadian Institutes of Health Research and the International Development Research Centre with assistance from Drs. Sally Humphries and Cate Dewey.

DATA COLLECTION:

Local support was provided by collaborators in the DHAN field office in Anchetty, including V. Vediyappan and M. Suresh. V. Vediyappan introduced me to T. Madhe Gowda, who provided translation and research assistance during the two qualitative studies (presented in Chapters 5 and 7) and during the larger cross-sectional quantitative study (presented in Chapters 3, 4, 6, and 7).

Qualitative studies (December 2012 – April 2013)

I spearheaded the snowball and convenience sampling methods. I was present for all interviews, focus groups, and validation methods, and provided input and prompts as necessary. T. Madhe Gowda provided concurrent translation assistance and technical support. I transcribed semi-structured interviews immediately and quantified all quantifiable variables for further analysis.

Quantitative study (December 2013 – March 2014)

The research team for the quantitative project was comprised of five individuals, including the aforementioned T. Madhe Gowda. Mr. Gowda provided extensive logistical support and offered expertise and contextual knowledge for the systematic random sampling process. N. Kodhai Priya and Priscilla Dhanapal were registered dieticians and nutritionist and administered questionnaires, including the descriptive questionnaire, the GPAQ, and the FFQ. Priscilla Dhanapal also conducted anthropometric measurements on all female participants. Dr. Vikas Kumar was a physician and conducted anthropometric measurements on all male participants and collected and analyzed all blood samples and blood pressure measurements until early January 2014, after which he was removed from the project for reasons unrelated to his performance. From this point forward, Mr. R. Rajesh, a trained nurse, was responsible for conducting anthropometric measurements on all male participants and collecting and analyzing all blood samples and blood pressure measurements. I organized the systematic random sampling process and oversaw the administration of all quantitative questionnaires and collection of anthropometric and clinical data.

DATA ANALYSIS AND WRITING:

I conducted all data entry and data cleaning activities. I analyzed all qualitative data in NVivo 10 (QSR International 2012) with support from Dr. Sally Humphries. I analyzed all quantitative data in Microsoft Excel 10.0 (Microsoft 2011) and STATA 13.0 (StataCorp 2012) with assistance from Drs. Cate Dewey, Scott McEwen, David Pearl, and Warren Dodd. I was responsible for preparing all manuscripts included in this dissertation, with editing and revisions from Drs. Cate Dewey, Sally Humphries, Kirit Patel, and Warren Dodd.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE:

TYPE 2 DIABETES: A GLOBAL HEALTH EMERGENCY

1.1 Introduction

Diabetes is considered one of the principal threats to human health of the 21st century (Zimmet 2000). Over the past three decades, there has been a drastic increase in global incidence and mortality due to diabetes. The number of individuals with diabetes has risen from 188 million in 1980 to 422 million in 2014 (World Health Organization 2016a). This represents an almost two-fold rise in global prevalence among adults over the age of 18 from 4.7% to 8.5% (ibid) and has been classified as an epidemic by World Health Organization (WHO) (WHO 2014), the International Diabetes Federation (Webber 2011), the American Diabetes Association (ADA) (Wild et al. 2004), and several other respected organizations and scholars (Bonow & Gheorghiade 2004; Canadian Diabetes Association 2011; Zimmet 2001). A broad range of factors has driven the explosive global increase of diabetes. These factors are primarily associated with changes in the human environment, and in behaviour and lifestyle, that have accompanied globalization (Zimmet 2001). Diabetes is not only a problem in high-income countries; indeed, low- and middle-income countries in Latin America, Africa, and Asia are bearing the brunt of the diabetes epidemic, and in many regions, the disease has overwhelmed the capacity of healthcare systems and carries severe economic repercussions (WHO 2016a).

1.2 Defining diabetes

Diabetes mellitus is a metabolic disorder characterized by inadequate regulation of blood glucose. Under normal conditions, pancreatic beta cells (β-cells) secrete insulin in response to high blood sugar following food consumption. Insulin is an anabolic hormone that promotes absorption of glucose from the blood stream into the fat, liver, and skeletal muscle cells, where it is converted to glycogen or fat (triglycerides). Insulin also inhibits glucose excretion into the blood by the liver and promotes the synthesis of proteins in a wide variety of tissues (Sonksen & Sonksen 2000). There are two primary forms of diabetes. Diabetes mellitus type 1 (also known as type 1 diabetes) is an autoimmune condition characterized by β-cell deficiency in the pancreatic islets, leading to lower-than-normal secretion of insulin (Daneman 2006). Type 1 diabetes comprises approximately 10% of the global diabetes burden (WHO 2016b). By contrast, diabetes mellitus type 2 (known as type 2 diabetes) is characterized by a combination of insulin resistance, β-cell destruction, and β-cell dysfunction, which often leads to hyperinsulinemia (high amounts of circulating insulin) and hyperglycaemia (high blood glucose levels) (Draznin et al. 2011). Type 2 diabetes comprises the large majority of the global diabetes burden and is the primary form of diabetes in the current global diabetes epidemic (WHO 2016b). This dissertation will focus exclusively on type 2 diabetes. The abbreviated term, 'diabetes' will refer to type 2 diabetes from this point forward.

1.3 Symptoms and progression of diabetes

Noticeable clinical symptoms of diabetes include excessive urination (polyuria), persistent thirst (polydipsia), weight loss, hunger, and fatigue (WHO 2016b). These symptoms may occur suddenly, or may appear more gradually. Undiagnosed, unmanaged, or progressive diabetes leads to hyperglycaemia, which may result in micro- (capillary) and macrovascular (arteries and veins) damage and subsequent complications (Draznin et al. 2011). Etiological mechanisms for vascular damage are complex and varied, and include promotion of production of advanced-glycation end products, elevated production of reactive oxygen species, impaired vasodilatory response attributable to nitric oxide inhibition, smooth muscle dysfunction, impaired fibrinolytic ability, and enhanced platelet aggregation (Cade 2008). Diabetes-induced vascular damage is referred to as vascular disease and is comprised of both micro- and macrovascular complications (Draznin et al. 2011).

1.3.1 Microvascular complications: Retinopathy, nephropathy, and neuropathy

Diabetic retinopathy (DR) is a microvascular complication characterized by damage to the light-sensitive tissues at the back of the eye. Retinal vessel leakage and ensuing muscular edema may cause central vision loss. In extreme cases, retinal detachment or vitreous hemorrhaging may cause total vision loss (Sheetz & King 2002). Diabetic retinopathy accounts for 2.6% of blindness globally (WHO 2016b). Prevalence estimates of DR amongst individuals with diabetes vary widely between populations, and range from 17.6% in a study in India (Rema et al. 2005) to 33.2% in a large US study (Wong et al. 2006). DR risk increases with duration of diabetes (Kempen et al. 2004). A population-based study in the US showed that people diagnosed with diabetes over the age of 30 were at lowest risk of developing DR, while those diagnosed younger exhibited higher incidence (Klein et al. 1991). In addition, epidemiology studies on individuals with diabetes have found associations between DR and poor blood sugar control, male sex (Scanlon et al. 2013), tobacco usage, abnormal blood lipid profile, high-fat diet, pregnancy, and renal disease (Cundiff & Nigg 2005; Cusick et al. 2003).

Diabetic nephropathy (DN) is a severe complication of T2D, characterized by kidney dysfunction caused by damage to the capillaries of the glomeruli. DN initially appears as microalbuminuria (above-normal albumin in the urine) and progresses to overt albuminuria (severely elevated levels of albumin in the urine, also known as macroalbuminuria) (Cade 2008). DN is the leading cause of end-stage renal disease (Sun et al. 2013). End-stage renal disease leads to kidney failure if not addressed with dialysis or a kidney transplant. According to cohort studies, approximately 25% of people with diabetes have microalbuminuria or more severe forms of DN, and these conditions tend to worsen over time (Adler et al. 2003). DN is the leading global cause of kidney disease, and is responsible for 44% of deaths due to kidney failure (ADA 2016). Five to ten percent of individuals with diabetes will die due to DN (Lerma & Batuman 2014). Risk factors for DN among diabetes patients include hyperglycemia, age of onset, duration of diabetes, dyslipidemia, hypertension, and obesity (Hasslacher et al. 1989).

Diabetic neuropathy generally presents as peripheral neuropathy (PN), which is characterized by damage to the nerves of the peripheral nervous system due to damage to the capillaries that supply nerves (Draznin et al. 2011). Diabetes-associated PN can have wide-ranging symptoms, including numbness in extremities, dizziness and balance problems, muscle weakness, diarrhea, and speech impairment. PN in the lower extremities, coupled with impaired vascular function can contribute to foot ulceration (Boulton 1997; Reiber et al. 1995). Autonomic neuropathy is also a common complication of diabetes, including cardiovascular autonomic dysfunction (AD). AD includes clinical abnormalities such as tachycardia (high resting heart rate), resting heart rate variability, orthostasis ("head rushes"), "silent" myocardial infarction (severe myocardial ischemia with no chest pain), and increased risk of mortality (Cade 2008; Vinik & Zeigler 2007).

1.3.2 Macrovascular complications: Cardiovascular disease, cerebrovascular disease, and peripheral artery disease

Diabetes is also associated with structural and functional macrovascular issues leading to multi-organ dysfunction (Rahman et al. 2007). People with diabetes frequently have many traditional risk factors for cardiovascular disease (CVD), including central obesity, dyslipidemia (i.e. elevated serum triglyceride, free fatty acid levels and low-density lipoproteins, as well as low high-density lipoprotein), and hypertension. These risk factors, working independently or in combination with type 2 diabetes, can significantly increase risk of CVD (Reusch 2007). Approximately 70% of people with diabetes over the age of 65 die from cardiovascular disease, while 16% die from stroke (American Heart Association 2015). People with diabetes are four times more likely to have a severe CVD event after controlling for traditional risk factors (Bonora et al. 2002; Buyken et al. 2007). In addition, individuals with diabetes have a five-fold greater risk for a first myocardial infarction (MI, commonly known as a heart attack) and a two-fold greater risk for a recurrent MI than individuals without diabetes (Haffner et al. 1998).

Diabetes is also an independent risk factor for cerebrovascular disease (CD), which is narrowing of arteries supplying blood to the brain. CD can lead to stroke; indeed, people with diabetes have an estimated three-fold greater risk of stroke (Centers for Disease Control and Prevention 2016), as well as higher risk of risk of recurrent strokes and mortality from a stroke (Tuomilehto et al. 2006), a greater tendency for severe neurological disabilities from strokes (Di Carlo et al. 2006), and poorer long-term post-stroke prognoses (Sprafka et al. 1994) when compared to individuals without diabetes.

Finally, macrovascular damage can lead to constriction and occlusion of arteries supplying blood to the lower extremities, which is called peripheral artery disease (PAD). PAD can cause claudication (cramping pain) in the legs, often induced by exercise (National Institutes of Health 2016). PAD and associated pain can progress to cause functional impairments and disability (McDermott et al. 2004). In severe cases, and in combination with PN, PAD may result in foot ulceration and lower-extremity amputation (Adler et al. 1999). Individuals with diabetes are 15 times more likely to have foot or leg amputations than people without diabetes (Adler et al. 1999). Presence and severity of PAD is associated with duration of diabetes and poor blood sugar control (Jude et al. 2001).

1.4 Etiology of diabetes

Researchers have identified a wide variety of risk factors as being associated with onset and mismanagement of type 2 diabetes. Risk factors fall into four categories: (1) obesity; (2) genetic, prenatal, and neonatal factors; (3) lifestyle factors, including physical activity, diet, and smoking habits; and (4) stress.

1.4.1 Obesity

Obesity and diabetes are inextricably linked, and so often occur in tandem that researchers have coined the term "diabesity" (Astrup & Finer 2000). Risk of type 2 diabetes rises drastically with increasing body-mass index (BMI, calculated as weight divided by height squared). While specific populations may differ, in the United States a BMI of 25-30 kg/m^2 confers a 1.5-fold greater lifetime risk of diabetes than a BMI of 18.5-25 kg/m^2, while a BMI between 30-35 kg/m^2 confers a 3-fold greater lifetime risk of diabetes, and a BMI above 35 kg/m^2 confers a 4-fold greater lifetime risk of diabetes (Narayan et al. 2007). Pathophysiological reasons for this association are varied and complex. Adipose tissue affects metabolism by secreting hormones and other substances including cytokines, adiponectin, and proinflammatory substances, and non-esterified fatty acids (NEFAs), all of which play a role in insulin resistance (Kahn et al. 2006). High NEFA levels also contribute to β-cell dysfunction (Kahn 2001).

Recently, researchers have observed that abdominal (also known as visceral, central, or ectopic) body fat is better associated with cardio-metabolic risk in comparison to general adiposity as measured by BMI (Huxley et al. 2010). Central adiposity has been highlighted as a growing problem, especially among Asian populations where individuals may have a normal BMI but exhibit a larger waist circumference (WC) and larger waist-to-hip circumference ratio (WHR) than European populations. As a result, some researchers argue for WC and WHR as replacements for BMI in determining risk of diabetes (Cheng et al. 2010; Huxley et al. 2008). So far, however, there is no consensus among researchers on this topic, and due to ease of assessment and precedence, BMI is still widely used (Huxley et al. 2010).

1.4.2 Genetic predisposition and prenatal and neonatal factors

Diabetes shows a familial clustering pattern, indicating that genetic variants play a strong role in onset and prognosis (Martin et al. 1992). Indeed, several genetic loci are associated with risk of diabetes, while dozens of others have been identified as potentially associated (Sladek et al. 2007). Furthermore, certain ethnic groups are susceptible to diabetes, including North American Aboriginals (Gohdes 1995), Australian Aborigines (Guest & O'Dea 1992), Pacific Islanders (Karter et al. 2013), African-Americans (Marshall 2005), and south Asian populations (Karter et al. 2013), and often in both native and migrant populations. Individuals with diabetes from susceptible ethnic groups frequently display higher rates of cardio-metabolic risk factors and illnesses compared to European populations, including greater abdominal obesity (Misra et al. 2005), high blood pressure, and poor lipid profile.

The 'thrifty genotype' hypothesis, promoted by James Neel in 1962, proposes an explanation for the increased susceptibility of certain ethnic groups (Neel 1962). Neel's theory postulates that hunter-gatherer societies favored a genotype that promoted fat deposition and storage of calories in times of plenty. This genotype would confer a survival benefit during regular famines; however, when these populations have a constant and plentiful supply of calories, it may become a handicap, and result in obesity, type 2 diabetes, and other metabolic disorders (Dowse & Zimmet 1993). Thus populations that until recently were prone to famine may be more susceptible to diabetes. Since Neel first proposed the hypothesis, geneticists (Auwerx 1999; Tabarin et al. 2005), epidemiologists (Zimmet et al. 2001), and medical researchers (Lazar 2005) have promoted evidence to support his proposal. However, the thrifty genotype hypothesis has been criticized for various reasons, including its contributions to the racialization of diabetes (Paradies et al. 2007; Poudrier 2007), its inability to account for historical famine cycles amongst European and other 'non-thrifty' populations (Speakman 2008), and a lack of sufficient genetic (and other) evidence (Ayub et al. 2014; Gosling et al. 2015; Steinthorsdottir et al. 2014). Nevertheless, thrifty genes are still viewed as a powerful explanation for ethnic predisposal to diabetes by many leading researchers (Yajnik 2004; Zimmet et al. 2001).

Prenatal and early childhood conditions and nutrition are associated with risk of diabetes. Most notably, low birth weight has been linked with risk of diabetes in adulthood in North America (Dyck et al. 2001; McCance et al. 1994), Europe (Wang et al. 2016), India (Fall et al. 1998), China (Tian et al. 2006), and Taiwan (Wei et al. 2003). To explain this association, Hales and Barker introduced the 'thrifty phenotype' hypothesis in 1992 as an alternative (but not contradictory) hypothesis to Neels' thrifty genotype. Hales and Barker's (1992) hypothesis suggests that under-nutrition acts as an early environmental influence, inducing alterations of physiology in early life and rendering individuals more susceptible to obesity and diabetes later in life. Such environmental determinants may include in-utero birth environment (e.g. hyperglycemia or hyperinsulinemia), as well as early childhood nutrition. For example, breast-feeding in the first two months of life is associated with reduced risk of diabetes (Pettitt et al. 1997; von Kries et al. 1999). The thrifty phenotype hypothesis has detractors and limitations (see Lindsay and Bennett 2001 for a list of challenges), but is still held as a leading hypothesis by many for explaining the recent epidemic of diabetes, particularly in low- and middle-income countries undergoing rapid economic development (Yajnik 2004).

1.4.3 Behavioural factors: Physical activity, diet, and tobacco use

Behavioural lifestyle factors also play a role in risk of diabetes. Physical activity, based on self-reported, tracked, or prescribed activity, as well as cardiorespiratory fitness, are negatively associated with incidence risk of diabetes (Carnethon et al. 2003; Paffenbarger et al. 1993; Sawada et al. 2003). Two successive studies by Manson et al. (1991; 1992) reported that both women and men who conducted vigorous activity at least once per week had an approximately 33% lower risk of developing diabetes. This association remained after adjustment for BMI. Relatedly, sedentary habits have been independently linked with diabetes; a meta-analysis of prospective epidemiological data revealed that the greater sedentary time was associated with a two-fold increased risk of diabetes and cardiovascular mortality, even after controlling for physical activity and BMI (Wilmot et al. 2012).

While diet and nutrition are influential in the development of diabetes, controversy exists about specific dietary factors that increase or reduce risk. Yao et al. (2014) conducted a meta-analysis of prospective study data and determined that dietary fiber, cereal fiber, fruit fiber, and insoluble fiber were all protective against risk of diabetes. Two large prospective cohort studies on women have found an inverse association between whole grain consumption and risk of diabetes (Liu et al. 2000; Meyer et al. 2000). In a large systematic review, Hu et al. (2001) found that long-chain n-3 fatty acids (such as those found in fish) could be beneficial, whereas high intakes of saturated fats and trans-fats could adversely affect glucose metabolism. Similarly, Estruch et al. (2006) found that a Mediterranean diet (high in monounsaturated fatty acids, n-3 fatty acids, fiber, and antioxidants) reduced mean plasma glucose levels compared to the control diet in a large randomized trial, indicating that such a diet may be protective against the development of diabetes. Van Dam et al. (2006) found that long-term coffee consumption is associated with lower risk of diabetes. Meanwhile, consumption of sugar-sweetened drinks (Palmer et al. 2008), fast food (Pereira et al. 2005), and refined grains (Aune et al. 2013; Mohan et al. 2010; Radhika et al. 2009) have all been linked with increased risk of diabetes.

In 1981, Köster et al. (1981) proposed the glycemic index (GI) as a method of quantifying the ability of certain foods to elevate blood glucose levels after consumption. The GI of foods is multifactorial, and is determined by nutrition content, structure, processing, and preparation methods. Foods containing added sugars, as well as starchy foods (e.g. white bread, white rice, cooked potatoes) have high GI values, while whole-grain cereals and breads, nuts, and legumes have lower glycemic indices despite similar carbohydrate contents (Maki 2004). The concept of glycemic load (GL) factors in both glycemic index and absolute carbohydrate content (Ludwig 2002). Epidemiologic and clinical evidence demonstrate that high dietary glycemic load is associated with elevated risk of diabetes (Barclay et al. 2008). A high GL meal induces higher postprandial glucose, greater demand on pancreatic β -cells, and amplified insulin secretion (Willett et al. 2002). As such, some researchers have theorized that a high GL diet may simultaneously overtax β -cells (leading to decreased capacity for insulin secretion) and diminish tissue sensitivity to insulin (Maki 2004).

There are some preliminary data on the potential effects of vitamins, nutrients, and contaminants, however this research is plagued by small sample sizes and conflicting results. Montonen et al. (2004) found that vitamin E intake, as well as consumption of some anti-oxidants (alpha-tocopherol, gamma-tocopherol, sigma-tocopherol, and β -tocotrienol) were inversely associated with risk of diabetes among a cohort of Dutch and Finnish participants. Vitamin C was inversely associated with incident cases of diabetes in a cohort of individuals in London; however, the authors admitted that this association might be confounded by other macro- and micronutrients common in fruit and vegetable (Harding et al. 2008). There exists some evidence to suggest that zinc intake is inversely associated with diabetes risk (Singh et al. 1998). Research in Europe, the United States, and the Canadian Arctic have linked contaminants such as arsenic (Navas-Acien et al. 2008;), mercury (He et al. 2013; Salonen et al. 1995; Virtanen et al. 2007), and organic pollutants and agricultural chemicals (Lee et al. 2006) to heightened risk of diabetes, but most of these were cross-sectional studies with limited capacity to determine causation. The effects of many contaminants on diabetes risk are prone to interaction and confounding, making them difficult to study (He et al. 2013); as such, further research is needed to elucidate potential metabolic effects.

Wei and colleagues (2000) determined a U-shaped relationship between alcohol intake and incidence of diabetes, with non-drinkers and heavy drinkers (>10 drinks/week) being at higher risk after adjusting for multiple anthropometric and lifestyle risk factors. Other studies, both observational and experimental, have corroborated that moderate drinking may confer a protective effect against diabetes (e.g. Gepner et al. 2015; Rasouli et al. 2013), but there is debate about the effect of high levels of alcohol consumption and binge drinking on risk of diabetes (Cullmann et al. 2012). Therefore, more data are needed to confirm and determine mechanisms for this association.

Cigarette smoking and other forms of tobacco consumption are important risk factors for diabetes. Large prospective studies have produced convincing evidence that cigarette smoking is associated with a two-fold increase in risk of diabetes among both men (Rimm et al.

1995) and women (Rimm et al. 1993). Some recent evidence suggests that exposure to second-hand smoke (Kim et al. 2016) and parental smoking during pregnancy (Montgomery & Ekbom 2002) elevates risk of diabetes. Smokeless tobacco is also associated with diabetes; evidence from Sweden (Persson et al. 2000) and the US (Gupta et al. 2004) indicates that use of 'snus' and other forms of chewing tobacco increases likelihood of diabetes by up to four times over never-users of tobacco.

1.4.4 Stress

Psychological stress has been cited as a risk factor in several studies on explanatory models amongst individuals with diabetes in Latin America (Baer et al. 2003; Little 2012), India (Mendenhall et al. 2012), and Southeast Asia (Naemiratch & Manderson 2007), as well as immigrant communities in North America (Hatcher & Whittemore 2007) and Europe (Greenhalgh et al. 1998). Recently, biomedical literature has produced epidemiological evidence linking specific stressors (for example, job strain, low social support, and clinical depression) to increased risk of type 2 diabetes (Heraclides et al. 2009; Knol et al. 2006; Norberg et al. 2007). Researchers speculate that stress induces secretion of cortisol, which stimulates glucose production and antagonizes insulin action. Chronic psychological stress may therefore overburden glucose metabolic cycles (McEwen 1998; Tabák et al. 2009). Despite biological plausibility, evidence of a stress-diabetes association remains scarce and inconsistent (Fransson et al. 2012; Heraclides et al. 2009; Norberg et al. 2007).

1.5 Diagnosing glucose tolerance status

There are three diagnostic categories of abnormal glucose metabolism: impaired glucose tolerance, impaired fasting glucose, and type 2 diabetes.

1.5.1 Impaired glucose tolerance and impaired fasting glucose (pre-diabetes)

Impaired glucose tolerance (IGT) is hyperglycemia with plasma glucose values above normal, but below diabetes following a glucose load. IGT represents a key stage in the natural progression to type 2 diabetes; approximately 50% of people with IGT progress to diabetes within 10 years (however, some may also revert to normal or remain IGT) (Zimmet et al. 2001). People with IGT also have heightened risk of macrovascular disease and cardiovascular events (Tominaga et al. 1999).

Impaired fasting glucose (IFG) is higher-than-normal fasting glucose, and was introduced recently as another category of abnormal glucose metabolism (WHO 2006). Like IGT, IFG is associated with higher risk of CVD and future diabetes. IGT is a better predictor than IFG of future diabetes and mortality. The existence of IGT and/or IFG is often considered 'pre-diabetes'.

1.5.2 Diagnostic testing

High blood glucose is the hallmark of IGT, IFG, and type 2 diabetes. Direct measurement of blood glucose using either a fasting plasma blood glucose (FPG) test or an oral glucose tolerance test (OGTT) remains the mainstay for diagnostic testing. FPG is obtained by measuring plasma glucose concentration in a venous or capillary blood sample following a minimum 8-hour fast (WHO 2006), and is the recommended test by the American Diabetes Association (ADA 2004a). An OGTT begins with an initial FPG test. Following this measurement, the participant consumes a 75-gram anhydrous glucose (dextrose) load. Two-hours post-load, another blood sample is taken and the post-prandial blood glucose concentration is measured again (WHO 2003). Despite its relatively higher margin of error, capillary blood sampling is common practice in under-resourced settings due to simplicity and its tendency to produce higher response rates (WHO 2006).

Following a FPG test or OGTT, glucose tolerance status is determined using criteria presented in Table 1.1. Based on an extensive review of current epidemiological studies for risk of adverse outcomes, WHO and ADA promote similar (but still notably different) definitions for impaired fasting glucose, impaired glucose tolerance, and type 2 diabetes. While there is debate about the necessity of the OGTT in clinical and epidemiological settings (Goldstein et al. 2004), the WHO continues to recommend this test, particularly since fasting plasma glucose alone fails to diagnose approximately 30% of cases of previously undiagnosed diabetes, and OGTTs are the only tests that can identify people with impaired glucose tolerance (WHO 2006).

1.5.3 The potential of glycated hemoglobin for diagnosing diabetes

Glycated hemoglobin (HbA1c) is a biomarker that shows potential for use in diagnostic testing, as its concentration in blood plasma reflects average plasma glucose over the previous 2-3 months in a single measure and does not require fasting (Bennett et al. 2007). HbA1c is the gold standard for assessing glycaemic management in patients with diagnosed diabetes. However, due to the lack of measurement techniques and equipment in many countries, as well as its susceptibility to influence by several factors including pregnancy and anemia (Goldstein et al. 2004), the WHO does not recommend HbA1c assessment as a diagnostic test (WHO 2006).

1.6 Management and treatment of type 2 diabetes

The three primary management goals for individuals with type 2 diabetes are: intensive lifestyle interventions, including physical activity, weight loss, and a calorie-reduced low-fat diet; management of diabetes-associated cardiovascular risk factors (hypertension, dyslipidemia, and microalbuminuria) using medications like aspirin and statins; and normalization of blood glucose levels with medications and insulin injections (Ripsin et al. 2009). Most treatment plans involve a number of simultaneous lifestyle and medical interventions.

1.6.1 Lifestyle changes

The two most common lifestyle intervention recommendations are physical activity and dietary changes, with goals of glycemic control and weight reduction in overweight or obese patients. Physical activity has been shown to improve glycaemic control and insulin sensitivity (Thomas et al. 2007). In many cases, physical activity leads to lower central adiposity, weight loss, lower blood pressure, and improvements in lipid profiles (Miller et al. 2002), which are beneficial for patients' long-term prognosis. A systematic review found that exercise interventions reduced HbA1C levels by 0.6 percent, and triglyceride levels and visceral adiposity were reduced independent of BMI (Thomas et al. 2007). Dietary intervention (often called nutrition therapy) is important, both for achieving or maintaining a healthy body weight, and to directly reduce hyperglycemia. Effective dietary interventions include increased intake of whole grains (which are associated with improved insulin sensitivity) and high fibre intake (which improves insulin secretion) (Liese et al. 2003). Individuals with type 2 diabetes are encouraged to reduce energy intake and limit consumption of simple sugars, saturated and trans fatty acids, cholesterol, sodium, and alcohol to improve glucose homeostasis, reduce dyslipidemia, and control blood pressure (American Diabetes Association 2008). Reducing the consumption of foods with high glycemic loads will improve long-term glucose homeostasis and reduce hyperglycemia (Riccardi et al. 2008). These interventions may also promote weight loss, which will improve long-term prognosis for diabetes patients (Strychar 2006). Patient-specific dietary modifications may limit the detrimental effects of diabetes complications such as nephropathy and CVD (ADA 2008).

1.6.2 Management of CVD risk factors

Interventions to manage CVD risk factors (hypertension, dyslipidemia, and microalbuminuria) in patients with type 2 diabetes are important to reduce the risk of CVD and complications associated with hyperglycemia, thus improving long-term health and reducing mortality risk (Gæde et al. 2003). The American Diabetes Association (ADA) recommends daily low-dose aspirin (a vasodilator) to reduce the risk of adverse cardiovascular complications (ADA 2004b), however clinical trial data on the protective effects of aspirin are inconclusive (Ogawa et al. 2008). Statins (a class of drugs used to lower blood cholesterol) are also recommended for patients with type 2 diabetes who are also at risk of CVD (ADA 2008). Angiotensin-converting enzyme (ACE) inhibitors, angiotensin receptor blockers, and other hypertension-reducing drugs are often used to lower blood pressure, and also appear to protect diabetes patients from nephropathy (Highlander & Shaw 2010).

1.6.3 Normalization of blood glucose levels

Decreased insulin secretion, insulin resistance, and increased hepatic glucose secretion are the three primary defects that cause hyperglycemia in people with type 2 diabetes. Each class of diabetes medication targets at least one of these defects. The most common class of medication are biguanides (also known as metformin) that decrease glucose output by the liver and sensitize peripheral tissues to insulin, and have been shown to reduce mortality rates in patients with type 2 diabetes (Goodman et al. 2005; UKPDS 1998). Insulin secretagogues (also known as sulfonylureas) induce the pancreas to secrete more insulin (Goodman et al. 2005). Thiazolidinediones, similar to metformin, sensitize the body's tissues to the effects of insulin

(Nissen and Wolski 2007). Several other medications exist that stimulate insulin secretion, decrease glucagon secretion, and slow glucose absorption in the small intestine.

A patient's treatment plan often consists of a number of different oral medications in combination to address multiple defects. However, progressive failure of the β-cells often occurs despite proper lifestyle and medication therapy, and in these cases, insulin therapy can be employed as another management tool (Ripsin et al. 2009). Insulin therapy is also a viable therapy technique during pregnancy because of the potential teratogenicity (fetal harm) of oral medications (Ripsin et al. 2009). Available insulin and insulin analogues include those that are administered prior to meals, and those with regular dosage schedules (e.g. once or twice daily) (Hirsch et al. 2005).

1.7 The global epidemic of diabetes

Diabetes is an enormous (and growing) global clinical and public health problem. Rising prevalence and incidence data have driven the World Health Organization (WHO 2014), the International Diabetes Federation (Webber 2011), the American Diabetes Association (Wild et al. 2004), and several other high-profile organizations and scholars (Bonow & Gheorghiade 2004; Canadian Diabetes Association 2011; Zimmet et al. 2001) to declare a global 'epidemic' of diabetes with severe public health and economic implications. The etiology of the current global epidemic is complex, rooted in global economic growth and livelihood and cultural changes spurred by the nutrition transition.

1.7.1 Global prevalence: past, present, and future

The global prevalence of diabetes has doubled since 1980, rising from 4.7% to 8.5% (WHO 2016a). In 2015, the International Diabetes Federation (IDF) estimated that 415 million adults had diabetes globally (IDF 2015). Prevalence varies drastically between countries, continents, and ethnic groups. Pacific Island countries have some of the highest prevalences of diabetes (upwards of 25%, and sometimes as high as 40%), followed by many countries in the Middle East, including Saudi Arabia and Kuwait (where prevalences are 24% and 23% respectively) (Guariguata et al. 2014). The vast majority of people with diabetes live in low- and middle-income countries. China currently has the most people with diabetes, with over 98.4 million adults with the disease (Yang et al. 2010); this is closely followed by India, with 65.1 million (Anjana et al. 2011). Undiagnosed diabetes is a major concern; the IDF approximates that 46.5% of people with diabetes are currently undiagnosed (including two thirds of diabetics in Africa and over half in south Asia), which represents a portion of the population that is at high risk of complications (IDF 2016). See Table 1.2 for a summary of global diabetes prevalence.

In 2012, diabetes was the eighth leading cause of death among both sexes and the fifth leading cause of death in women (WHO 2016a), with 1.5 million deaths worldwide caused by diabetes directly. This accounts for 7% of deaths among men aged 20-69 and 8% among women aged 20-69. This percentage is higher in low- and middle-income countries than high-income countries. In 2012, a further 2.2 million deaths were caused by CVD, chronic kidney disease, and other complications related to higher-than-optimal blood glucose (WHO 2016a).

The diabetes epidemic is expected to continue. Economic development, globalization, and lifestyle, livelihood, and cultural shift due to the nutrition transition will contribute to rising rates of diabetes for decades to come (IDF 2015). High prevalence of impaired fasting glucose (IFG) and impaired glucose tolerance (IGT) expose the likelihood for further increases in the global burden of diabetes. Global prevalence of combined IFG and/or IGT is approximately 7.8%, with higher prevalence in Africa (8.2%) and North America (10.8%) (Shaw et al. 2010).

Individuals with IFG and/or IGT are often considered ‘pre-diabetic’, and exhibit a 50% likelihood of developing overt diabetes within 10 years (Nichols et al. 2007), as well as increased risk of CVD (Perry & Baron 1999). By 2040, the IDF estimates that there will be 640 million people with diabetes in the world (IDF 2015). The greatest projected 10-year increases are expected in low-income countries (108%), followed by lower middle-income countries (60%) and upper middle-income countries (51%) (Guariguata et al. 2014).

1.7.2 Economic burden of diabetes

Beyond the impacts on individuals, the diabetes epidemic imposes a considerable economic burden on societies. Costs include increased use of health services, loss of productivity, and disability. Health care expenditures for people with diabetes are two to three-fold higher than for those without diabetes (ADA 2012; Yang et al. 2012). Costs associated with diabetes accounted for about 12% of global healthcare expenditure in 2015 (IDF 2016). Over 80% of countries dedicated between 5 and 20% of their total health expenditure to diabetes, including preventive and curative services (IDF 2016). Approximately USD$2000 per person with diabetes was spent globally on treating and managing the disease in 2015, however only 19% of this was spent in low- and middle-income countries, despite these countries containing 75.4% of people with diabetes (IDF 2016). People with diabetes living in low- and middle-income countries generally pay a larger out-of-pocket share of health expenditure due to poorer health insurance and public medical services (Barcelo et al. 2003).

Diabetes also leads to loss in economic growth and productivity. The ADA estimates that the US economy lost $69 billion in reduced productivity due to diabetes in 2012, which include increased absenteeism, reduced productivity for the employed population, reduced productivity due to disability, and lost productive capacity due to early mortality (ADA 2012).

The WHO estimates net losses in national income from diabetes of USD$557.7 billion in China, USD$236.6 billion in India, USD$49.2 in Brazil, and USD$303.2 billion in Russia between 2005 and 2015 (Zhang et al. 2010).

1.8 Etiology of the diabetes epidemic

Individual risk factors for type 2 diabetes were described in detail above. However, despite our knowledge of the multifactorial etiology of diabetes, researchers are often faced with more relevant public health quandaries, for example: which factors are causing the global epidemic of diabetes? What processes are most relevant in creating environments that promote diabetes risk factors? And, what can be done to reduce the burden of diabetes? The answers to these questions will inevitably vary depending on the population of interest, but must necessarily involve a discussion about social, economic, and political systems that drive more proximate risk factors (Lancet 2010). This discussion must supersede traditional notions of individual biological causality to examine the "ecosocial and other emerging multi-level frameworks…to integrate social and biological reasoning and a dynamic historical and ecological perspective to develop new insights into determinants of population distributions of disease and social inequalities in health" (Candib 2007; Krieger 2001).

In both developed and developing nations, diabetes is a marker of shifting environments, health inequalities, and economic, food, and health policy (Candib 2007). Obesity is one of the strongest predictors of diabetes, and risk factors for obesity overlap with those already mentioned – notably, diet and physical activity. The dramatic rise in obesity, diabetes, and related disorders is related to rapid changes in lifestyle and diet that have occurred among certain segments of the global population in the past 50 years. Interestingly, these changes have manifested in different ways in the high-income countries when compared to low- and middle-income countries.

1.8.1 Diabetes in high-income countries

In developed countries in North America and Europe, as well as Australia and some South American nations, obesity and diabetes disproportionately affect low-income populations (Agardh et al. 2011; Jaffiol et al. 2013). Low income, poor access to (and affordability of) nutritious food, shifts in low-skilled jobs from labour to service-based, and chronic stress all create an environment for low-income populations that is conducive to promoting more proximate risk factors for obesity and diabetes. In the United States, individuals with lower income and less education are two to four times more likely to develop diabetes than more advantaged individuals (Agardh et al. 2011). Diabetes can exacerbate or initiate a cycle of poverty and poor health for several reasons. First, the financial burden of increased health care costs can intensify the effects poverty. Second, disadvantaged individuals may lack access to resources necessary to manage their condition. And third, diabetes can reduce an individual's capacity to work or attain education, leading to further poverty, deprivation, and social exclusion (Candib 2007).

1.8.2 Diabetes in low- and middle-income countries

The diabetes epidemic transpires differently in developing country contexts. Nations in Asia, Africa, and Latin America are currently undergoing epidemiologic and nutrition transitions, characterized by increased life expectancy and lower birth rates (leading to greater incidence and prevalence of age-related disorders like diabetes), increased access and availability of foods, including those high in processed fats and carbohydrates and low in fiber, and reduced physical activity due to shifting livelihoods and mechanization of labour. The result is often a shift from infectious diseases to noncommunicable diseases as the dominant sources of morbidity and mortality (Mattei et al. 2015). This transition often first permeates the affluent classes of developing countries, although more recently it is apparent that rural poor populations are also affected, albeit at lower prevalence (Mohan et al. 2007). Occasionally, as has been reported in several countries, the burden of obesity and cardio-metabolic diseases rise without a corresponding decline of under-nutrition and micronutrient deficiencies, leading to what researchers call the 'double burden' of disease. This will be described in further detail in Chapters 2, 6, and 7.

1.9 Conclusion

Type 2 diabetes is a global problem with severe public health and economic repercussions. Under the leadership of the World Health Organization, more than 190 countries agreed on global mechanisms to reduce non-communicable disease burden, including a global action plan for the prevention and control of diabetes 2013-2020 (WHO 2015). Despite this, based on current trends, and high global prevalence of pre-diabetes, several international organizations and leading researchers believe that diabetes prevalence will continue to rise for the foreseeable future.

The adverse effects of diabetes on mortality, morbidity, and development are clear. Worldwide, diabetes disproportionately affects vulnerable populations, often with severe impacts on individuals, families, and healthcare systems. Complications often limit the productive capacity of individuals and increase healthcare-related costs, initiating or enforcing a cycle of poverty for families in high-income and low-income countries alike.

While there has been substantial research on this issue, the diabetes epidemic is extremely complex and multifactorial. There still exist enormous gaps in our collective knowledge about the mechanisms of diabetes, the root genetic and environmental causes, and distal cultural, socioeconomic, and policy factors that contribute to risk factors, and appropriate interventions and clinical practice. An enormous effort is required by the global public health and research communities to understand and begin to address the global epidemic of diabetes.

REFERENCES

Adler, A. I., Boyko, E. J., Ahroni, J. H., & Smith, D. G. (1999). Lower-extremity amputation in diabetes. The independent effects of peripheral vascular disease, sensory neuropathy, and foot ulcers. *Diabetes care*, *22*(7), 1029-1035.

Adler AI, Stevens RJ, Manley SE, Bilous RW, Cull CA, Holman RR, UKPDS GROUP. (2003). Development and progression of nephropathy in type 2 diabetes: the United Kingdom Prospective Diabetes Study (UKPDS 64). *Kidney International*; *63*(1):225-32.

Agardh, E., Allebeck, P., Hallqvist, J., Moradi, T., & Sidorchuk, A. (2011). Type 2 diabetes incidence and socio-economic position: a systematic review and meta-analysis. *International Journal of Epidemiology*, *201*:1-15.

American Diabetes Association. (2004a). Screening for type 2 diabetes. *Diabetes Care*, *27*(suppl 1), s11-s14.

American Diabetes Association. (2004b). Aspirin therapy in diabetes. *Diabetes Care*, *27*(suppl 1), s72-s73.

American Diabetes Association. (2008). Nutrition recommendations and interventions for diabetes. *Diabetes Care*, *31*(Supplement 1), S61-S78.

American Diabetes Association. (2012). The cost of diabetes. Available at : http://www.diabetes.org/advocacy/news-events/cost-of-diabetes.html. Accessed 29 March 2017.

American Diabetes Association. (2013). Economic costs of diabetes in the US in 2012. *Diabetes Care; 36*(6), 1033–1046.

American Diabetes Association. (2016). Statistics about diabetes. Available at: http://www.diabetes.org/diabetes-basics/statistics/. Accessed 7 February 2017.

American Heart Association. (2015). Cardiovascular Disease & Diabetes. Available at: http://www.heart.org/HEARTORG/Conditions/More/Diabetes/WhyDiabetesMatters/Cardiovascular-Disease-Diabetes_UCM_313865_Article.jsp/#.WNvaF3Tyvow. Accessed 3 February 2017.

Anjana, R. M., Pradeepa, R., Deepa, M., Datta, M., Sudha, V., et al. (2011). Prevalence of diabetes and prediabetes (impaired fasting glucose and/or impaired glucose tolerance) in urban and rural India: Phase I results of the Indian Council of Medical Research–INdia DIABetes (ICMR–INDIAB) study. *Diabetologia*, *54*(12), 3022-3027.

Astrup, A., & Finer, N. (2000). Redefining type 2 diabetes: 'diabesity' or 'obesity dependent diabetes mellitus'? *Obesity Reviews*, *1*(2), 57-59.

Aune, D., Norat, T., Romundstad, P., & Vatten, L. J. (2013). Whole grain and refined grain consumption and the risk of type 2 diabetes: a systematic review and dose–response meta-analysis of cohort studies. *European Journal of Epidemiology*, *28*(11), 845-858.

Auwerx, J. (1999). PPARγ, the ultimate thrifty gene. *Diabetologia*, *42*(9), 1033-1049.

Ayub, Q., Moutsianas, L., Chen, Y., Panoutsopoulou, K., Colonna, V., et al. (2014). Revisiting the thrifty gene hypothesis via 65 loci associated with susceptibility to type 2 diabetes. *The American Journal of Human Genetics*, *94*(2), 176-185.

Baer, R. D., Weller, S. C., de Alba Garcia, J. G., Glazer, M., Trotter, R., Pachter, L., & Klein, R. E. (2003). A cross-cultural approach to the study of the folk illness nervios. *Culture, Medicine and Psychiatry*, *27*(3), 315-337.

Barcelo, A., Aedo, C., Rajpathak, S., & Robles, S. (2003). The cost of diabetes in Latin America and the Caribbean. *Bulletin of the World Health Organization*, *81*(1), 19-27.

Barclay, A. W., Petocz, P., McMillan-Price, J., Flood, V. M., Prvan, T., Mitchell, P., & Brand-Miller, J. C. (2008). Glycemic index, glycemic load, and chronic disease risk—a meta-analysis of observational studies. *The American Journal of Clinical Nutrition*, *87*(3), 627-637.

Bennett, C. M., Guo, M., & Dharmage, S. C. (2007). HbA1c as a screening tool for detection of type 2 diabetes: a systematic review. *Diabetic Medicine*, *24*(4), 333-343.

Bonora, E., Formentini, G., Calcaterra, F., Lombardi, S., Marini, F., et al. (2002). HOMA-estimated insulin resistance is an independent predictor of cardiovascular disease in type 2 diabetic subjects prospective data from the Verona Diabetes Complications Study. *Diabetes Care*, *25*(7), 1135-1141.

Bonow, R. O., & Gheorghiade, M. (2004). The diabetes epidemic: a national and global crisis. *The American Journal of Medicine*, *116*(5), 2-10.

Boulton AJ. (1997). Foot problems in patients with diabetes mellitus. In: Pickup J, Williams G, ed. Textbook of Diabetes. London, United Kingdom: Blackwell Science, 1–58.

Buyken, A. E., von Eckardstein, A., Schulte, H., Cullen, P., & Assmann, G. (2007). Type 2 diabetes mellitus and risk of coronary heart disease: results of the 10-year follow-up of the PROCAM study. *European Journal of Cardiovascular Prevention & Rehabilitation*, *14*(2), 230-236.

Cade, W. T. (2008). Diabetes-related microvascular and macrovascular diseases in the physical therapy setting. *Physical Therapy*, *88*(11), 1322-1335.

Canadian Diabetes Association (2011). Diabetes: Canada at the Tipping Point. Available at: http://www.diabetes.ca/publications-newsletters/advocacy-reports/diabetes-canada-at-the-tipping-point. Accessed 8 Jan 2017.

Candib, L. M. (2007). Obesity and diabetes in vulnerable populations: reflection on proximal and distal causes. *The Annals of Family Medicine*, *5*(6), 547-556.

Carnethon, M. R., Gidding, S. S., Nehgme, R., Sidney, S., Jacobs Jr, D. R., & Liu, K. (2003). Cardiorespiratory fitness in young adulthood and the development of cardiovascular disease risk factors. *Journal of the American Medical Association*, *290*(23), 3092-3100.

Centers for Disease Control and Prevention. (2016) Stroke. Available at: http://www.cdc.gov/stroke/. Accessed 8 Jan 2017.

Cheng, C. H., Ho, C. C., Yang, C. F., Huang, Y. C., Lai, C. H., & Liaw, Y. P. (2010). Waist-to-hip ratio is a better anthropometric index than body mass index for predicting the risk of type 2 diabetes in Taiwanese population. *Nutrition Research*, *30*(9), 585-593.

Cullmann, M., Hilding, A., & Östenson, C. G. (2012). Alcohol consumption and risk of pre-diabetes and type 2 diabetes development in a Swedish population. *Diabetic Medicine*, *29*(4), 441-452.

Cundiff, D. K., & Nigg, C. R. (2005). Diet and diabetic retinopathy: insights from the Diabetes Control and Complications Trial (DCCT). *Medscape General Medicine*, *7*(1), 3.

Cusick, M., Chew, E. Y., Chan, C. C., Kruth, H. S., Murphy, R. P., & Ferris, F. L. (2003). Histopathology and regression of retinal hard exudates in diabetic retinopathy after reduction of elevated serum lipid levels. *Ophthalmology*, *110*(11), 2126-2133.

Daneman, D. (2006). Type 1 diabetes. *The Lancet*, *367*(9513), 847-858.

Di Carlo, A., Lamassa, M., Baldereschi, M., Pracucci, G., Consoli, D., et al. (2006). European BIOMED Study of Stroke Care Group Risk factors and outcome of subtypes of ischemic stroke. Data from a multicenter multinational hospital-based registry. The European Community Stroke Project. *Journal of Neurological Science*, *15*(244), 1-2.

Dowse, G., & Zimmet, P. (1993). The thrifty genotype in non-insulin dependent diabetes. *British Medical Journal*, *306*(6877), 532.

Draznin, B., Epstein, S., Turner, H.E., & Wass, J.A.H. (2011). Oxford American Handbook of Endocrinology and Diabetes. New York: Oxford University Press.

Dyck RF, Klomp H, Tan L. (2001)From “thrifty genotype” to “hefty fetal phenotype”: the relationship between high birthweight and diabetes in Saskatchewan Registered Indians. *Canadian Journal of Public Health 92*:340-4.

Estruch, R., Martínez-González, M. A., Corella, D., Salas-Salvadó, J., Ruiz-Gutiérrez, et al. (2006). Effects of a Mediterranean-style diet on cardiovascular risk factors: a randomized trial. *Annals of Internal Medicine*, *145*(1), 1-11.

Fall, C. H. D., Stein, C. E., Kumaran, K., Cox, V., Osmond, C., Barker, D. J. P., & Hales, C. N. (1998). Size at birth, maternal weight, and type 2 diabetes in South India. *Diabetic Medicine*, *15*(3), 220-227.

Fransson, E., Heikkilä, K., Nyberg, S., Zins, M., Westerlund, H., et al. (2012). Job strain as a risk factor for leisure-time physical inactivity: an individual-participant meta-analysis of up to 170,000 men and women: the IPD-Work Consortium. *American Journal of Epidemiology, 176*(12), 1078-89.

Gæde, P., Vedel, P., Larsen, N., Jensen, G. V., Parving, H. H., & Pedersen, O. (2003). Multifactorial intervention and cardiovascular disease in patients with type 2 diabetes. *New England Journal of Medicine*, *348*(5), 383-393.

Gepner, Y., Golan, R., Harman-Boehm, I., Henkin, Y., Schwarzfuchs, D., et al. (2015). Effects of initiating moderate alcohol intake on cardiometabolic risk in adults with type 2 diabetes: a 2-year randomized, controlled trial. *Annals of Internal Medicine*, *163*(8), 569-579.

Gohdes, D. (1995). Diabetes in North American Indians and Alaska Natives. *Atlantic*, *43*, 87.

Goldstein DE, Little RR, Lorenz RA, Malone JI, Nathan D, Peterson CM, Sacks DB. (2004). Tests of glycemia in diabetes. *Diabetes Care, 27*: 1761-1773.

Goodman, L. S., Gilman, A. Z., Brunton, L. L. (2005). *Goodman & Gilman's The Pharmacological Basis of Therapeutics*. 11th ed. New York, NY: McGraw-Hill.

Gosling, A. L., Buckley, H. R., Matisoo-Smith, E., & Merriman, T. R. (2015). Pacific Populations, Metabolic Disease and 'Just-So Stories': A Critique of the 'Thrifty Genotype'Hypothesis in Oceania. *Annals of human genetics*, *79*(6), 470-480.

Greenhalgh, T., Helman, C., & Chowdhury, A. M. M. (1998). Health beliefs and folk models of diabetes in British Bangladeshis: a qualitative study. *British Medical Journal*, *316*(7136), 978-983.

Guariguata, L., Whiting, D. R., Hambleton, I., Beagley, J., Linnenkamp, U., & Shaw, J. E. (2014). Global estimates of diabetes prevalence for 2013 and projections for 2035. *Diabetes Research and Clinical Practice*, *103*(2), 137-149.

Guest, C. S., & O'Dea, K. (1992). Diabetes in Aborigines and other Australian populations. *Australian Journal of Public Health*, *16*(4), 340-349.

Gupta, R., Gurm, H., & Bartholomew, J. R. (2004). Smokeless tobacco and cardiovascular risk. *Archives of internal medicine*, *164*(17), 1845-1849.

Haffner, S. M., Lehto, S., Rönnemaa, T., Pyörälä, K., & Laakso, M. (1998). Mortality from coronary heart disease in subjects with type 2 diabetes and in nondiabetic subjects with and without prior myocardial infarction. *New England Journal of Medicine*, *339*(4), 229-234.

Hales, C. N., & Barker, D. J. (1992). Type 2 (non-insulin-dependent) diabetes mellitus: the thrifty phenotype hypothesis. *Diabetologia*, *35*(7), 595-601.

Harding, A. H., Wareham, N. J., Bingham, S. A., Khaw, K., Luben, R., Welch, A., & Forouhi, N. G. (2008). Plasma vitamin C level, fruit and vegetable consumption, and the risk of new-onset type 2 diabetes mellitus: the European prospective investigation of cancer–Norfolk prospective study. *Archives of Internal Medicine*, *168*(14), 1493-1499.

Hasslacher, C. H., Ritz, E., Wahl, P., & Michael, C. (1989). Similar risks of nephropathy in patients with type I or type II diabetes mellitus. *Nephrology Dialysis Transplantation*, *4*(10), 859-863.

Hatcher, E., & Whittemore, R. (2007). Hispanic adults' beliefs about type 2 diabetes: Clinical implications. *Journal of the American Academy of Nurse Practitioners*, *19*(10), 536-545.

He, K., Xun, P., Liu, K., Morris, S., Reis, J., & Guallar, E. (2013). Mercury Exposure in Young Adulthood and Incidence of Diabetes Later in Life The CARDIA Trace Element Study. *Diabetes Care*, *36*(6), 1584-1589.

Heraclides, A., Chandola, T., Witte, D. R., & Brunner, E. J. (2009). Psychosocial stress at work doubles the risk of type 2 diabetes in middle-aged women evidence from the whitehall II study. *Diabetes Care*, *32*(12), 2230-2235.

Highlander, P., & Shaw, G. P. (2010). Current pharmacotherapeutic concepts for the treatment of cardiovascular disease in diabetics. *Therapeutic Advances in Cardiovascular Disease*, *4*(1), 43-54.

Hirsch, I. B., Bergenstal, R. M., Parkin, C. G., Wright, E., & Buse, J. B. (2005). A real-world approach to insulin therapy in primary care practice. *Clinical Diabetes*, *23*(2), 78-86.

Hu, F. B., Van Dam, R. M., & Liu, S. (2001). Diet and risk of type II diabetes: the role of types of fat and carbohydrate. *Diabetologia*, *44*(7), 805-817.

Huxley, R., James, W. P. T., Barzi, F., Patel, J. V., Lear, S. A., et al. (2008). Ethnic comparisons of the cross-sectional relationships between measures of body size with diabetes and hypertension. *Obesity Reviews*, *9*(s1), 53-61.

Huxley, R., Mendis, S., Zheleznyakov, E., Reddy, S., & Chan, J. (2010). Body mass index, waist circumference and waist: hip ratio as predictors of cardiovascular risk—a review of the literature. *European Journal of Clinical Nutrition*, *64*(1), 16-22.

International Diabetes Federation. (2015). IDF Diabetes Atlas, 7th ed. Available at: http://www.diabetesatlas.org. Accessed 14 Jan 2017.

Jaffiol, C., Thomas, F., Bean, K., Jégo, B., & Danchin, N. (2013). Impact of socioeconomic status on diabetes and cardiovascular risk factors: results of a large French survey. *Diabetes & Metabolism*, *39*(1), 56-62.

Jenkins, D. J., Wolever, T. M., Taylor, R. H., Barker, H., Fielden, H., et al . (1981). Glycemic index of foods: a physiological basis for carbohydrate exchange. *The American Journal of Clinical Nutrition*, *34*(3), 362-366.

Jude, E. B., Oyibo, S. O., Chalmers, N., & Boulton, A. J. (2001). Peripheral Arterial Disease in Diabetic and Nondiabetic Patients A comparison of severity and outcome. *Diabetes Care*, *24*(8), 1433-1437.

Kahn, S. E. (2001). The importance of β-cell failure in the development and progression of type 2 diabetes. *The Journal of Clinical Endocrinology & Metabolism*, *86*(9), 4047-4058.

Kahn, S. E., Hull, R. L., & Utzschneider, K. M. (2006). Mechanisms linking obesity to insulin resistance and type 2 diabetes. *Nature*, *444*(7121), 840-846.

Karter, A. J., Schillinger, D., Adams, A. S., Moffet, H. H., Liu, J., Adler, N. E., & Kanaya, A. M. (2013). Elevated Rates of Diabetes in Pacific Islanders and Asian Subgroups The Diabetes Study of Northern California (DISTANCE). *Diabetes Care*, *36*(3), 574-579.

Kempen J. H., O'Colmain, B. J., Leske, M. C., Haffner, S. M., Klein, R., et al., Eye Diseases Prevalence Research Group. (2004). The prevalence of diabetic retinopathy among adults in the United States. *Archives of Ophthalmology*, *122*(4), 552.

Kim, B. J., Sung, J. W., Kim, B. S., & Kang, J. H. (2016). GW27-eo548 Sex-specific relationship between cotinine-verified second-hand smoke exposure and metabolic syndrome in 85,698 never-smokers. *Journal of the American College of Cardiology*, *68*(16_S), C70-C71.

Knol, M. J., Twisk, J. W. R., Beekman, A. T. F., Heine, R. J., Snoek, F. J., & Pouwer, F. (2006). Depression as a risk factor for the onset of type 2 diabetes mellitus. A meta-analysis. *Diabetologia*, *49*(5), 837-845.

Krieger, N. (2001). Theories for social epidemiology in the 21st century: an ecosocial perspective. *International Journal of Epidemiology*, *30*(4), 668-677.

Lancet, (2010). Type 2 diabetes: Time to change our approach. *Lancet*, *375*:2193.

Lazar, M. A. (2005). How obesity causes diabetes: not a tall tale. *Science*, *307*(5708), 37.

Lee, D. H., Lee, I. K., Song, K., Steffes, M., Toscano, W., Baker, B. A., & Jacobs, D. R. (2006). A strong dose-response relation between serum concentrations of persistent organic pollutants and diabetes results from the National Health and Examination Survey 1999–2002. *Diabetes Care*, *29*(7), 1638-1644.

Lerma, E. V., & Batuman, V. (eds) (2014). Diabetes and Kidney Disease. Springer: New York.

Liese, A. D., Roach, A. K., Sparks, K. C., Marquart, L., D'Agostino Jr, R. B., & Mayer-Davis, E. J. (2003). Whole-grain intake and insulin sensitivity: the Insulin Resistance Atherosclerosis Study. *The American Journal of Clinical Nutrition*, *78*(5), 965-971.

Lindsay, R. S., & Bennett, P. H. (2001). Type 2 diabetes, the thrifty phenotype–an overview. *British Medical Bulletin*, *60*(1), 21-32.

Little, M. (2012). Type 2 Diabetes in Rural Guatemala: Disease Perceptions, Service-Provision Difficulties and Management Techniques. *Undercurrent Journal: Vol. 9, Issue 1 (Spring/Summer 2012)*, 24.

Liu, S., Manson, J. E., Stampfer, M. J., Hu, F. B., Giovannucci, E., et al. (2000). A prospective study of whole-grain intake and risk of type 2 diabetes mellitus in US women. *American Journal of Public Health*, *90*(9), 1409.

Ludwig, D. S. (2002). The glycemic index: physiological mechanisms relating to obesity, diabetes, and cardiovascular disease. *Journal of the American Medical Association*, *287*(18), 2414-2423.

Maki, K. C. (2004). Dietary factors in the prevention of diabetes mellitus and coronary artery disease associated with the metabolic syndrome. *The American Journal of Cardiology*, *93*(11), 12-17.

Manson, J. E., Nathan, D. M., Krolewski, A. S., Stampfer, M. J., Willett, W. C., & Hennekens, C. H. (1992). A prospective study of exercise and incidence of diabetes among US male physicians. *Journal of the American Medical Association*, *268*(1), 63-67.

Manson, J. E., Stampfer, M. J., Colditz, G. A., Willett, W. C., Rosner, B., et al. (1991). Physical activity and incidence of non-insulin-dependent diabetes mellitus in women. *The Lancet*, *338*(8770), 774-778.

Marshall, M. C. (2005). Diabetes in African Americans. *Postgraduate Medical Journal*, *81*(962), 734-740.

Martin, B. C., Warram, J. H., Rosner, B., Rich, S. S., Soeldner, J. S., & Krolewski, A. S. (1992). Familial clustering of insulin sensitivity. *Diabetes, 41*(7), 850-854.

Mattei, J., Malik, V., Wedick, N. M., Hu, F. B., Spiegelman, D., Willett, W. C., & Campos, H. (2015). Reducing the global burden of type 2 diabetes by improving the quality of staple foods: The Global Nutrition and Epidemiologic Transition Initiative. *Globalization and Health*, *11*(1), 1.

McCance, D. R., Pettitt, D. J., Hanson, R. L., Jacobsson, L. T., Knowler, W. C., & Bennett, P. H. (1994). Birth weight and non-insulin dependent diabetes: thrifty genotype, thrifty phenotype, or surviving small baby genotype? *British Medical Journal*, *308*(6934), 942-945.

McDermott, M. M., Liu, K., Greenland, P., Guralnik, J. M., Criqui, M. H., et al. (2004). Functional decline in peripheral arterial disease: associations with the ankle brachial index and leg symptoms. *Journal of the American Medical Association*, *292*(4), 453-461.

McEwen, B. S. (1998). Protective and damaging effects of stress mediators. *New England Journal of Medicine*, *338*(3), 171-179.

Mendenhall, E., Shivashankar, R., Tandon, N., Ali, M. K., Narayan, K. V., & Prabhakaran, D. (2012). Stress and diabetes in socioeconomic context: A qualitative study of urban Indians. *Social Science & Medicine*, *75*(12), 2522-2529.

Meyer, K. A., Kushi, L. H., Jacobs, D. R., Slavin, J., Sellers, T. A., & Folsom, A. R. (2000). Carbohydrates, dietary fiber, and incident type 2 diabetes in older women. *The American Journal of Clinical Nutrition*, *71*(4), 921-930.

Miller, E. R., Erlinger, T. P., Young, D. R., Jehn, M., Charleston, J., et al. (2002). Results of the diet, exercise, and weight loss intervention trial (DEW-IT). *Hypertension*, *40*(5), 612-618.

Misra, A., Wasir, J. S., & Vikram, N. K. (2005). Waist circumference criteria for the diagnosis of abdominal obesity are not applicable uniformly to all populations and ethnic groups. *Nutrition*, *21*(9), 969-976.

Mohan, V., Radhika, G., Vijayalakshmi, P., & Sudha, V. (2010). Can the diabetes/cardiovascular disease epidemic in India be explained, at least in part, by excess refined grain (rice) intake. *Indian J Med Res, 131*:369-72.

Montgomery, S. M., & Ekbom, A. (2002). Smoking during pregnancy and diabetes mellitus in a British longitudinal birth cohort. *British Medical Journal*, *324*(7328), 26-27.

Montonen, J., Knekt, P., Järvinen, R., & Reunanen, A. (2004). Dietary antioxidant intake and risk of type 2 diabetes. *Diabetes Care*, *27*(2), 362-366.

Naemiratch, B., & Manderson, L. (2007). Lay explanations of type 2 diabetes in Bangkok, Thailand. *Anthropology & Medicine*, *14*(1), 83-94.

Narayan, K. V., Boyle, J. P., Thompson, T. J., Gregg, E. W., & Williamson, D. F. (2007). Effect of BMI on lifetime risk for diabetes in the US. *Diabetes care*, *30*(6), 1562-1566.

National Institutes of Health. (2016). What is peripheral artery disease? Available at: https://www.nhlbi.nih.gov/health/health-topics/topics/pad. Accessed 8 January 2017.

Navas-Acien, A., Silbergeld, E. K., Pastor-Barriuso, R., & Guallar, E. (2008). Arsenic exposure and prevalence of type 2 diabetes in US adults. *JAMA*, *300*(7), 814-822.

Nichols, G. A., Hillier, T. A., & Brown, J. B. (2007). Progression from newly acquired impaired fasting glusose to type 2 diabetes. *Diabetes Care*, *30*(2), 228-233.

Nissen, S. E., & Wolski, K. (2007). Effect of rosiglitazone on the risk of myocardial infarction and death from cardiovascular causes. *New England Journal of Medicine*, *356*(24), 2457-2471.

Norberg, M., Stenlund, H., Lindahl, B., Andersson, C., Eriksson, J. W., & Weinehall, L. (2007). Work stress and low emotional support is associated with increased risk of future type 2 diabetes in women. *Diabetes Research and Clinical Practice*, *76*(3), 368-377.

Ogawa, H., Nakayama, M., Morimoto, T., Uemura, S., Kanauchi, M., et al. (Japanese Primary Prevention of Atherosclerosis With Aspirin for Diabetes Trial Investigators). (2008). Low-dose aspirin for primary prevention of atherosclerotic events in patients with type 2 diabetes: a randomized controlled trial. *Journal of the American Medical Association*, *300*(18), 2134-2141.

Palmer, J. R., Boggs, D. A., Krishnan, S., Hu, F. B., Singer, M., & Rosenberg, L. (2008). Sugar-sweetened beverages and incidence of type 2 diabetes mellitus in African American women. *Archives of Internal Medicine*, *168*(14), 1487-1492.

Paffenbarger Jr, R. S., Blair, S. N., Lee, I. M., & Hyde, R. T. (1993). Measurement of physical activity to assess health effects in free-living populations. *Medicine and Science in Sports and Exercise*, *25*(1), 60-70.

Paradies, Y., Montoya, M. J., & Fullerton, S. M. (2007). Racialized genetics and the study of complex diseases: the thrifty genotype revisited. *Perspectives in Biology and Medicine*, *50*(2), 203-227.

Pereira, M. A., Kartashov, A. I., Ebbeling, C. B., Van Horn, L., Slattery, M. L., Jacobs, D. R., & Ludwig, D. S. (2005). Fast-food habits, weight gain, and insulin resistance (the CARDIA study): 15-year prospective analysis. *The Lancet*, *365*(9453), 36-42.

Perry, R. C., & Baron, A. D. (1999). Impaired glucose tolerance. Why is it not a disease? *Diabetes Care*, *22*(6), 883-885.

Persson, P. G., Carlsson, S., Svanström, L., Östenson, C. G., Efendic, S., & Grill, V. (2000). Cigarette smoking, oral moist snuff use and glucose intolerance. *Journal of Internal Medicine*, *248*(2), 103-110.

Pettitt, D. J., Forman, M. R., Hanson, R. L., Knowler, W. C., & Bennett, P. H. (1997). Breastfeeding and incidence of non-insulin-dependent diabetes mellitus in Pima Indians. *The Lancet*, *350*(9072), 166-168.

Poudrier, J. (2007). The geneticization of Aboriginal diabetes and obesity: Adding another scene to the story of the thrifty gene. *Canadian Review of Sociology/Revue Canadienne de Sociologie*, *44*(2), 237-261.

Radhika, G., Van Dam, R. M., Sudha, V., Ganesan, A., & Mohan, V. (2009). Refined grain consumption and the metabolic syndrome in urban Asian Indians (Chennai Urban Rural Epidemiology Study 57). *Metabolism*, *58*(5), 675-681.

Rahman, S., Rahman, T., Ismail, A. A. S., & Rashid, A. R. A. (2007). Diabetes‐associated macrovasculopathy: pathophysiology and pathogenesis. *Diabetes, Obesity and Metabolism*, *9*(6), 767-780.

Rasouli, B., Ahlbom, A., Andersson, T., Grill, V., Midthjell, K., Olsson, L., & Carlsson, S. (2013). Alcohol consumption is associated with reduced risk of Type 2 diabetes and autoimmune diabetes in adults: results from the Nord‐Trøndelag health study. *Diabetic Medicine*, *30*(1), 56-64.

Reiber, G. E., Boyko, E. J., & Smith, D. G. (1995). Lower extremity foot ulcers and amputations in diabetes. *Diabetes in America*, *2*, 409-427.

Rema, M., Premkumar, S., Anitha, B., Deepa, R., Pradeepa, R., & Mohan, V. (2005). Prevalence of diabetic retinopathy in urban India: the Chennai Urban Rural Epidemiology Study (CURES) eye study, I. *Investigative Ophthalmology & Visual Science*, *46*(7), 2328-2333.

Reusch, J. E. B., & Draznin, B. B. (2007). Atherosclerosis in diabetes and insulin resistance. *Diabetes*, *Obesity and Metabolism*, *9*(4), 455-463.

Riccardi, G., Rivellese, A. A., & Giacco, R. (2008). Role of glycemic index and glycemic load in the healthy state, in prediabetes, and in diabetes. *The American Journal of Clinical Nutrition*, *87*(1), 269S-274S.

Rimm, E. B., Chan, J., Stampfer, M. J., Colditz, G. A., & Willett, W. C. (1995). Prospective study of cigarette smoking, alcohol use, and the risk of diabetes in men. *BMJ*, *310*(6979), 555-559.

Rimm, E. B., Manson, J. E., Stampfer, M. J., Colditz, G. A., Willett, W. C., et al. (1993). Cigarette smoking and the risk of diabetes in women. *American Journal of Public Health*, *83*(2), 211-214.

Ripsin, C. M., Kang, H., & Urban, R. J. (2009). Management of blood glucose in type 2 diabetes mellitus. *American Family Physician*, *79*(1), 29-36.

Salonen, J. T., Seppänen, K., Nyyssönen, K., Korpela, H., Kauhanen, et al. (1995). Intake of mercury from fish, lipid peroxidation, and the risk of myocardial infarction and coronary, cardiovascular, and any death in eastern Finnish men. *Circulation*, *91*(3), 645-655.

Sawada, S. S., Lee, I. M., Muto, T., Matuszaki, K., & Blair, S. N. (2003). Cardiorespiratory Fitness and the Incidence of Type 2 Diabetes Prospective study of Japanese men. *Diabetes Care*, *26*(10), 2918-2922.

Scanlon, P. H., Aldington, S. J., & Stratton, I. M. (2013). Epidemiological issues in diabetic retinopathy. *Middle East African Journal of Ophthalmology*, *20*(4), 293.

Shaw, J. E., Sicree, R. A., & Zimmet, P. Z. (2010). Global estimates of the prevalence of diabetes for 2010 and 2030. *Diabetes Research and Clinical Practice*, *87*(1), 4-14.

Sheetz, M. J., & King, G. L. (2002). Molecular understanding of hyperglycemia's adverse effects for diabetic complications. *Journal of the American Medical Association*, *288*(20), 2579-2588.

Singh, R. B., Niaz, M. A., Rastogi, S. S., Bajaj, S., Gaoli, Z., & Shoumin, Z. (1998). Current zinc intake and risk of diabetes and coronary artery disease and factors associated with insulin resistance in rural and urban populations of North India. *Journal of the American college of Nutrition*, *17*(6), 564-570.

Sladek, R., Rocheleau, G., Rung, J., Dina, C., Shen, L., et al. (2007). A genome-wide association study identifies novel risk loci for type 2 diabetes. *Nature*, *445*(7130), 881-885.

Sonksen, P., & Sonksen, J. (2000). Insulin: understanding its action in health and disease. *British Journal of Anaesthesia*, *85*(1), 69-79.

Speakman, J. R. (2008). Thrifty genes for obesity, an attractive but flawed idea, and an alternative perspective: the 'drifty gene' hypothesis. *International Journal of Obesity*, *32*(11), 1611-1617.

Sprafka, J. M., Virnig, B. A., Shahar, E., & McGovern, P. G. (1994). Trends in diabetes prevalence among stroke patients and the effect of diabetes on stroke survival: the Minnesota Heart Survey. *Diabetic Medicine*, *11*(7), 678-684.

Steinthorsdottir, V., Thorleifsson, G., Sulem, P., Helgason, H., Grarup, N., et al. (2014). Identification of low-frequency and rare sequence variants associated with elevated or reduced risk of type 2 diabetes. *Nature Genetics*, *46*(3), 294-298.

Strychar, I. (2006). Diet in the management of weight loss. *Canadian Medical Association Journal*, *174*(1), 56-63.

Sun, Y. M., Su, Y., Li, J., & Wang, L. F. (2013). Recent advances in understanding the biochemical and molecular mechanism of diabetic nephropathy. *Biochemical and Biophysical Research Communications*, *433*(4), 359-361.

Tabák, A. G., Jokela, M., Akbaraly, T. N., Brunner, E. J., Kivimäki, M., & Witte, D. R. (2009). Trajectories of glycaemia, insulin sensitivity, and insulin secretion before diagnosis of type 2 diabetes: an analysis from the Whitehall II study. *The Lancet*, *373*(9682), 2215-2221.

Tabarin, A., Diz-Chaves, Y., del Carmen Carmona, M., Catargi, B., Zorrilla, E. P., Roberts, A. J., & Inoue, K. (2005). Resistance to Diet-Induced Obesity in μ-Opioid Receptor–Deficient Mice Evidence for a "Thrifty Gene". *Diabetes*, *54*(12), 3510-3516.

Tian, J. Y., Cheng, Q., Song, X. M., Li, G., Jiang, G. X., Gu, Y. Y., & Luo, M. (2006). Birth weight and risk of type 2 diabetes, abdominal obesity and hypertension among Chinese adults. *European Journal of Endocrinology*, *155*(4), 601-607.

Thomas, D. E., Elliott, E. J., & Naughton, G. A. (2007). Exercise for type 2 diabetes mellitus (Review). *Cochrane Library*, *2007*, 1-45.

Tominaga, M., Eguchi, H., Manaka, H., Igarashi, K., Kato, T. A. K. E. O., & Sekikawa, A. (1999). Impaired glucose tolerance is a risk factor for cardiovascular disease, but not impaired fasting glucose. The Funagata Diabetes Study. *Diabetes Care*, *22*(6), 920-924.

Tuomilehto, J., Rastenytė, D., Jousilahti, P., Sarti, C., & Vartiainen, E. (1996). Diabetes mellitus as a risk factor for death from stroke prospective study of the middle-aged Finnish population. *Stroke*, *27*(2), 210-215.

UK Prospective Diabetes Study (UKPDS) Group. (1998). Effect of intensive blood-glucose control with metformin on complications in overweight patients with type 2 diabetes (UKPDS 34). *The Lancet*, *352*(9131), 854-865.

Van Dam, R. M., Willett, W. C., Manson, J. E., & Hu, F. B. (2006). Coffee, Caffeine, and Risk of Type 2 Diabetes A prospective cohort study in younger and middle-aged US women. *Diabetes Care*, *29*(2), 398-403.

Vinik, A. I., & Ziegler, D. (2007). Diabetic cardiovascular autonomic neuropathy. *Circulation*, *115*(3), 387-397.

Virtanen, J. K., Rissanen, T. H., Voutilainen, S., & Tuomainen, T. P. (2007). Mercury as a risk factor for cardiovascular diseases. *The Journal of Nutritional Biochemistry*, *18*(2), 75-85.

Von Kries, R., Koletzko, B., Sauerwald, T., Von Mutius, E., Barnert, D., Grunert, V., & Von Voss, H. (1999). Breast feeding and obesity: cross sectional study. *BMJ*, *319*(7203), 147-150.

Wang, T., Huang, T., Li, Y., Zheng, Y., Manson, J. E., Hu, F. B., & Qi, L. (2016). Low birthweight and risk of type 2 diabetes: a Mendelian randomisation study. *Diabetologia*, *59*(9), 1920-1927.

Webber S. New IDF data reveals diabetes epidemic continues to escalate. Available at: http://www.idf.org/new-idf-data-reveals-diabetes-epidemic-continues-escalate. Accessed 13

Jan 2017.

Wild, S., Roglic, G., Green, A., Sicree, R., & King, H. (2004). Global prevalence of diabetes estimates for the year 2000 and projections for 2030. *Diabetes Care*, *27*(5), 1047-1053.

Wei, M., Gibbons, L. W., Mitchell, T. L., Kampert, J. B., & Blair, S. N. (2000). Alcohol intake and incidence of type 2 diabetes in men. *Diabetes Care*, *23*(1), 18-22.

Wei, J. N., Sung, F. C., Li, C. Y., Chang, C. H., Lin, et al. (2003). Low birth weight and high birth weight infants are both at an increased risk to have type 2 diabetes among schoolchildren in Taiwan. *Diabetes Care*, *26*(2), 343-348.

Willett, W., Manson, J., & Liu, S. (2002). Glycemic index, glycemic load, and risk of type 2 diabetes. *The American Journal of Clinical Nutrition*, *76*(1), 274S-280S.

Wilmot, E. G., Edwardson, C. L., Achana, F. A., Davies, M. J., Gorely, T., et al. (2012). Sedentary time in adults and the association with diabetes, cardiovascular disease and death: systematic review and meta-analysis. *Diabetologia*, *55*, 2895-2905.

Wong, T. Y., Klein, R., Islam, F. A., Cotch, M. F., Folsom, A. R., Klein, B. E., et al. Multi-Ethnic Study of Atherosclerosis (MESA). (2006). Diabetic retinopathy in a multi-ethnic cohort in the United States. *American Journal of Ophthalmology*, *141*(3), 446-455.

World Health Organization. (2003). Screening for diabetes. Available at: http://www.who.int/diabetes/publications/en/screening_mnc03.pdf. Accessed 12 Jan 2017.

World Health Organization. (2006). Definition and diagnosis of diabetes mellitus and intermediate hyperglycaemia: report of a WH. Available at: http://apps.who.int/iris/bitstream/10665/43588/1/9241594934_eng.pdf. Accessed 12 Jan 2017.

World Health Organization. (2014). Mortality database. Geneva: World Health Organization; Available at: http://apps.who.int/ healthinfo/statistics/mortality/causeofdeath_query/. Accessed 12 January 2016.

World Health Organization. (2015). India: First to adapt global monitoring framework on noncommunicable diseases. Available at: http://www.who.int/features/2015/ncd-india/en/. Accessed 20 Jan 2017.

World Health Organization. (2016a). Global Report on Diabetes. Available at: http://apps.who.int/iris/bitstream/10665/204871/1/9789241565257_eng.pdf. Accessed 8 Jan 2017.

World Health Organization. (2016b). Diabetes fact sheet. Available at: http://www.who.int/mediacentre/factsheets/fs312/en/. Accessed 8 Jan 2017.

Yajnik, C. S. (2004). Early life origins of insulin resistance and type 2 diabetes in India and other Asian countries. *The Journal of Nutrition*, *134*(1), 205-210.

Yang, W., Lu, J., Weng, J., Jia, W., Ji, L., et al. (2010). Prevalence of diabetes among men and women in China. *New England Journal of Medicine*, *362*(12), 1090-1101.

Yang, W., Zhao, W., Xiao, J., Li, R., Zhang, P., Kissimova-Skarbek, K., et al. (2012). Medical care and payment for diabetes in China: enormous threat and great opportunity. *PloS one*, *7*(9), e39513.

Yao, B., Fang, H., Xu, W., Yan, Y., Xu, H., et al. (2014). Dietary fiber intake and risk of type 2 diabetes: a dose–response analysis of prospective studies. *European Journal of Epidemiology*, *29*(2), 79-88.

Zhang, P., Zhang, X., Brown, J., Vistisen, D., Sicree, R., Shaw, J., & Nichols, G. (2010). Global healthcare expenditure on diabetes for 2010 and 2030. *Diabetes Research and Clinical Practice*, *87*(3), 293-301.

Zimmet, P. (2000). Globalization, coca‐colonization and the chronic disease epidemic: can the Doomsday scenario be averted? *Journal of Internal Medicine*, *247*(3), 301-310.

Zimmet, P., Alberti, K. G. M. M., & Shaw, J. (2001). Global and societal implications of the diabetes epidemic. *Nature*, *414*(6865), 782-787.

TABLES

Table 1.1: Diagnostic criteria for diabetes, impaired glucose tolerance, and impaired fasting glucose according to the World Health Organization and the American Diabetes Association[1]

	WHO 1999 & 2006	**ADA 2003**
Diabetes		
Fasting glucose	≥7.0 mmol/L (126 mg/dL) **OR**	≥7.0 mmol/L (126 mg/dL) **OR**
2-h glucose	≥11.1 mmol/L (200 mg/dL)	≥11.1 mmol/L (200 mg/dL)
Impaired glucose tolerance (IGT)		
Fasting glucose	<7.0 mmol/L (126 mg/dL) (if measured) **AND**	Not required
2-h glucose	≥7.8 and <11.1 mmol/L (≥126 mg/dL and <200 mg/dL)	≥7.8 and <11.1 mmol/L (≥126 mg/dL and <200 mg/dL)
Impaired fasting glucose (IFG)		
Fasting glucose	6.1 to 6.9 mmol/L (110 mg/dL to 124 mg/dL) **AND** (if measured)	5.6 to 6.9 mmol/L (101 mg/dL to 124 mg/dL)
2-h glucose	<11.1 mmol/L (200 mg/dL)	Measurement not recommended

[1]Adapted from: World Health Organization. (2006). Definition and diagnosis of diabetes mellitus and intermediate hyperglycaemia: report of a WH. Available at: http://apps.who.int/iris/bitstream/10665/43588/1/9241594934_eng.pdf. Accessed 12 Jan 2017.

Table 1.2: Diabetes prevalence by global region for 2013[1]

Region	Population (20-79 Years) (millions)	Number of people with diabetes (20-79 years) (millions)	Comparative diabetes prevalence (20-79 years) (%)
Africa	407.8	19.8	5.7
Europe	658.7	56.3	6.8
Middle East and North Africa	347.5	34.6	10.9
North America and Caribbean	334.9	36.7	9.6
South and Central America	300.5	24.1	8.2
South-east Asia	883.2	72.1	8.7
West Pacific	1613.2	138.2	8.1
World	4572.9	381.8	8.3

[1]Prevalence estimates from: International Diabetes Federation. (2015). IDF Diabetes Atlas, 7th ed. Available at: http://www.diabetesatlas.org. Accessed 14 Jan 2017.

CHAPTER TWO:

TYPE 2 DIABETES IN INDIA: BURDEN, ETIOLOGY, AND CONTEXT

2.1 Introduction

Type 2 diabetes mellitus (diabetes) is an international epidemic with high morbidity and mortality and a large economic burden. Alarmingly, approximately 80% of cases are in low- and middle-income countries where diagnosis rates are low, healthcare investments are often inadequate, and preventive public health programming is scarce (IDF 2014). In India, while regional differences exist, national prevalence of diabetes has increased explosively in the past 40 years, from 1-2% to approximately 8%, with some urban areas experiencing prevalence as high as 14% (Sen et al. 2015).

The etiology of the diabetes epidemic in India is complex and multifactorial. Genetic factors play a role, along with environmental influences such as rising living standards, increased life expectancy, and India's recent 'nutrition transition', a term that encompasses shifting diets and declining physical activity that have driven a rise in obesity and associated health outcomes (Mohan et al. 2007). Researchers often blame urbanization, modernization, and globalization as more distal factors promoting the epidemic, but precise pathways of causation are unclear and understudied. Nonetheless, the consequences of diabetes are severe, both for individual patients and their families, and also for India's economy and healthcare system. If undiagnosed and/or untreated, diabetes can lead to complications such as cardiovascular disease (CVD), nephropathy, neuropathy, peripheral artery disease, and stroke, all of which may result in disability or death. Individuals with diabetes are often unable to work and incur significant costs associated with management of blood sugar levels and treatment of associated complications (Abegunde et al. 2007). The societal economic burden is severe, with estimates of healthcare expenses around US$2.2 billion annually, and likely much higher costs in lost productivity (Ramachandran 2007).

This chapter describes the diabetes epidemic in India. Drawing upon available information, prevalence estimates and trends are briefly discussed. We then summarize current research and hypotheses regarding the etiology of the diabetes epidemic, including political and socio-economic processes that may be contributing to more direct risk factors. Following this, we describe the current efforts to prevent and reduce the burden of diabetes in India. Finally, we examine how the diabetes epidemic contributes to the double burden of malnutrition in India, before describing research gaps and needs. Overall, this chapter describes the epidemiology of diabetes in India and provides justification for the primary research included in this dissertation.

2.2 Prevalence of diabetes in India: Trends and patterns

As early as 1982, Dr. Paul Zimmet, a leading global diabetes researcher, noted very high prevalence among Asian Indian migrant populations, leading him to suggest that they may have a greater susceptibility to diabetes than other ethnic groups (Zimmet 1982). Some researchers predicted, in light of this evidence, that diabetes would become a major problem in India as the country became more developed and industrialized (McKeigue, Shah, & Marmot 1991; Zimmet 1982). These predictions were proven prescient; and while prevalence data prior to 1970 are scarce, successive regional studies suggest that diabetes has been increasing since the mid-1970s, with an explosive rise since 1990. Most previous research has focused on urban areas where prevalence is higher. In 1973, over 19,000 urban individuals over the age of 15 were screened across six states using a stratified random design; prevalence of diabetes was 2.1% (Bhattacharya 2015). Consecutive cross-sectional data from clusters of adults in three urban neighbourhoods in Chennai in 1988 and 1993 suggested a rise in overall diabetes prevalence from 8.2% to 11.6% in just five years (Ramachandran et al. 1997a). In 2001, Misra and colleagues reported a prevalence of 11.2% in a random sample of individuals from urban slum population in northern India. In 2006, the large-scale Chennai Urban Rural Epidemiology Study (CURES), conducted by the Madras Diabetes Research Foundation (MDRF), found a prevalence of 14.3% among a random sample of adults in urban Chennai (Mohan et al. 2006). Other recent cross-sectional studies from urban areas of India have found prevalences of 12% in Puducherry (Bharati et al. 2011), 13.8% in Ahmedabad (Nayak et al. 2011), 18.6% in Chennai (Ramachandran et al. 2008), 13.5% in urban Jharkand (Anjana et al. 2011), and 14.2% in urban Chandigargh (Anjana et al. 2011).

While rural regions have lower prevalence, diabetes has nonetheless become a pervasive and increasing problem in these areas as well. In the early 1970s, the Indian Council of Medical Researchers conducted a prevalence study on clusters of adults (>15 years of age, sample size 15,117) from rural regions in six different states, and found an overall rural prevalence of 1.5% (Bhattacharya 2015). Cross-sectional epidemiological studies on random samples of adults from the early 1990s showed that prevalences were 4.9%, 4.6%, and 2.8% in rural regions of Tamil Nadu (Patandin et al. 1994), Punjab (Wander et al. 1994), and Uttar Pradhesh (Singh et al. 1998) respectively. A recent large-scale study conducted by Anjana et al. (2011) found prevalence of diabetes among adults (>19 years of age) was 7.8% in rural Tamil Nadu and 6.5% in rural Maharashtra. Other studies suggest that regional prevalence may be as high as 8-13% in some rural areas (Chow et al. 2007; Vijayakumar et al. 2009). Increasing prevalence of diabetes is particularly concerning when one considers that rural regions of India are home to over 70% of India's population and are plagued by low diagnosis rates, high rates of poverty, and poor access to healthcare services (Misra et al. 2011). Researchers agree that the prevalence of diabetes in urban and rural India is increasing rapidly, and predict that the epidemic will continue unabated unless immediate public health interventions are successfully implemented (Guariguata et al. 2014).

Similarly concerning are trends of impaired fasting glucose (IFG) and impaired glucose tolerance (IGT), together often called ‘pre-diabetes’ (WHO 2006). While estimates vary depending on region and diagnostic criteria, Misra and colleagues (2011) conducted a systematic review and found an increase in rural prevalence of IFG from the year 2000 onwards, especially among young adults. A national cross-sectional study in 2004 found prevalence of IFG was 2.5% (Sadikot et al. 2004), while more recent regional studies have determined a prevalence of 11.1% in Kashmir (Zargar et al. 2008) and 13.5% in Tamil Nadu (Balagopal et al. 2008). Meanwhile, a large-scale cross-sectional study by Anjana and colleagues (2011) found rural prevalences of pre-diabetes were 8.3%, 12.8%, 8.1%, and 14.1% in rural regions of Tamil Nadu, Maharashtra, Jharkhand, and Chandigarh, respectively (Anjana et al. 2011). Individuals with pre-diabetes have a 50% chance of developing overt diabetes within 10 years, so high rates of IFG and IGT are widely considered as harbingers of future increases in diabetes prevalence (Dinneen & Rizza 2007).

In addition to the rising prevalence of diabetes, some researchers have noted a decline in the average age of onset in India (Mohan et al. 2007). In India, the highest prevalence of diabetes is seen in the 40-64 year age group, whereas in many high-income western countries, individuals above the age of 65 are at the greatest risk (King et al. 1998). Mohan et al. (2006) have demonstrated that diabetes is increasing among younger age groups (Mohan et al. 2006). Indeed, at Dr. Mohan’s Diabetes Specialty Center in Chennai, the proportion of childhood-onset type 2 diabetes showed an increasing trend from 2001-2006 (although no more recent data are available) (Mohan et al. 2007). A hospital-based study in north India showed that a large number (8%) of all diabetes cases were youth (<18 years), indicating that childhood – onset type 2 diabetes is becoming a serious issue, similar to developed countries in Europe and North America (Bhatia et al. 2004; Rosenbloom et al. 1999). While more research is needed on diabetes among young people in India, if such trends are validated, this may be indicative of continued exacerbation of the diabetes epidemic.

2.3 Etiology of the diabetes epidemic in India

Why are Indians more prone to diabetes? Researchers have asked this question several times over the past three decades (Mohan et al. 2007; Mohan 2007; Raji et al. 2001; Sharp et al. 1987). Due to a strong interest from researchers working with native and migrant Indian populations around the world, several factors have been identified that begin to explain the epidemic of diabetes in India.

2.3.1 Genetic factors and the 'Asian Indian phenotype'

As with other populations, a strong familial aggregation of diabetes is observed among Asian Indians (Mohan et al. 1986). In 1985, Viswanathan et al. determined that diabetes was observed in 50% of Asian Indian offspring that had two parents with diabetes. This figure is higher than Europeans, among whom the risk of diabetes is 25% for offspring of two diabetics (UK Prospective Diabetes Study Group 1994).

Asian Indians possess several features that indicate that they are more prone to diabetes than other populations. Collectively, this ensemble of characteristics is referred to as the 'Asian Indian phenotype' (Mohan et al. 2007). A central feature of the Asian Indian phenotype is that Indian populations have a greater degree of insulin resistance compared to age, sex, and BMI matched Europeans (Laws et al. 1994; Raji et al. 2001; Sharp et al. 1987). Other anomalistic characteristics include higher central adiposity (Ramachandran et al. 1997b), decreased high-density lipoprotein cholesterol, high frequency of small low-density lipoprotein (Deepa et al. 2006; Joshi 2003), decreased adiponectin levels (Abate et al. 2004), and increased homocysteine levels (Chambers & Kooner 2002), all of which contribute to greater insulin resistance compared to European populations. Mohan et al. (1986) have demonstrated that Asian Indians produce significantly higher insulin levels for a given glucose load. Studies by Yajnik and colleagues found that low birth weight contributes to insulin resistance among Indians, and that Indian infants have higher insulin levels and greater adiposity at birth compared to Europeans (Yajnik et al. 1995; 2001; 2002). It is hypothesized that Indian infants with low birth weight have smaller muscle mass and abdominal viscera, but retain body fat *in utero*, which predisposes an insulin-resistant state (Yajnik et al. 2003). In addition, epidemiological and clinical evidence suggests that diabetes develops at a younger age in Indians than in Europeans (Mohan et al. 1985; Mohan et al. 2004). These data suggest that the Asian Indian phenotype predisposes Indians to diabetes, and small changes in lifestyle and environmental factors may trigger or 'uncover' this underlying genetic predisposition, resulting in diabetes onset.

2.3.2 The 'nutrition transition'

The 'nutrition transition' model, first proposed by Dr. Barry Popkin in 1993, describes several broad societal stages with different health and disease tendencies (Popkin 1993). Stages three through five are most relevant to present-day India. Stage three is a pattern of receding famine and rising incomes. In stage four, changes in diet (notably, increased intakes of fat, cholesterol, and refined carbohydrates and reduced consumption of polyunsaturated fatty acids and fiber) and decreased activity patterns lead to increased prevalence of obesity and metabolic diseases. Stage five involves increased intake of fruits and vegetables, complex carbohydrates, and reduced intake of refined foods, combined with increased recreational physical activity. These changes occur due to a renewed understanding of the importance of diet and physical activity in promoting health, and may be instituted by a combination of government policy and consumer behaviour. While the nutrition transition model has been criticized for lacking nuance (Lang & Rayner 2007), it is a useful starting point for examining socioeconomic, lifestyle, and dietary trends responsible for the epidemics of diabetes and obesity in India. This section will examine how the nutrition transition has transpired thus far in India.

2.3.2.1 Socio-economic transitions and urbanization

Socio-economic development over the last 40 years has dramatically shifted Indian lifestyles and livelihoods. Increased affluence has improved access to diets rich in fat, sugar, and calories (Misra et al. 2011b). Socioeconomic status has a strong association with diabetes risk both in urban and rural regions, suggesting that (contrary to developed countries) wealth is linked to lifestyles and habits conducive to the development of diabetes (Samuel et al. 2012). Meanwhile, increased urbanization, rural-urban migration, and globalization have promoted sedentary lifestyles, consumption of processed foods, and mental stress (Mohan et al. 2007). Urbanization has occurred rapidly in the past several decades – currently, 32% of the Indian population reside in urban areas, compared to 15% in the 1950s (Census India 2011). This could have major implications for diabetes in India, especially considering urban populations show higher prevalence of diabetes than their rural counterparts (Mohan et al. 2008). Indeed, urbanization is linked to a number of diabetes risk factors, including increased consumption of saturated fats and sugars and sedentary behaviour (Ebrahim et al. 2011).

2.3.2.2 Obesity and physical activity

The role of obesity in diabetes pathogenesis is complex and population-dependent. Chandalia et al. (1999) have shown that for any BMI, immigrant Indian populations have higher adiposity (body fat), and for any given body fat, they have higher insulin resistance compared to other ethnic groups. A prominent characteristic of the Asian Indian phenotype is the higher percentage body fat at a lower BMI value, higher proportions of visceral (abdominal) adiposity for a given BMI, high waist hip ratio at a relatively low waist circumference, and less lean body mass as compared to other ethnic groups (Joshi 2003). This phenotype is associated with higher risk of cardiovascular disease, stroke, and diabetes (Deepa et al. 2006). Such phenomena are well documented, and as a result the WHO has recommended lower BMI cut-offs for overweight among Indian populations (Misra et al. 2002; WHO 2004).

Consistent with research in other nations around the world, physical inactivity is associated with higher risk of obesity and diabetes in both urban and rural India. The Chennai Urban Population Study (CUPS) found that prevalence of diabetes was significantly higher among subjects that participated in light grade physical activity (17%), compared to moderate grade (9.7%) and heavy grade (5.6%) (Mohan et al. 2003). Several studies have found that urbanization promotes sedentary behaviour due to less physically demanding occupations and increased availability of mechanized transport (Anjana et al. 2014; Yadav & Krishnan 2008). While data on physical activity trends from rural regions are scarce, there is some quantitative and qualitative evidence to suggest that technological advancement and mechanization of agriculture and transportation, as well as the rising popularity of temporary labour migration, have led to decreased physical activity (Anjana et al. 2014). The WHO recommends at least 150 minutes of moderate to vigorous physical activity per week to reduce risk of non-communicable diseases, however less than 50% of individuals in India achieve this (although 77.4% of rural men, and 55.1% of rural women do) (Anjana et al. 2014). Interestingly, a recent national survey found that more than 90% of individuals in both urban and rural areas reported doing no *recreational* physical activity, which is likely reflective of a lack of facilities (Anjana et al. 2014) and little cultural importance (Lawton et al. 2006; Little et al. 2016a). This suggests that India is currently in stage four of Popkin's nutrition transition model, and has not yet widely adopted the leisure physical activity that characterize stage five. The obesity and diabetes epidemics will therefore likely continue until policy and behavioural interventions succeed in promoting healthy dietary and physical activity habits.

2.3.2.3 Dietary factors: Proximate and distal

After decades of regional famines, India was approaching adequacy in calorie intakes during the 1970s and early 1980s. National Nutrition Monitoring Bureau (NNMB) surveys showed a gradual improvement in per capita caloric intake, due primarily to increased consumption of cereal grains (Shetty 2002). Since 1980, there was a gradual reduction in cereal grain consumption while energy intake remained relatively stable; this is likely the result of improved dietary diversity, including intake of protein and fats (including milk products, fats, and oils) (Kumar & Dey 2007).

There is consensus in the literature that diets across India have shifted dramatically in recent decades, characterized by an overall decline in the per capita consumption of traditional grains and a diversification of food consumption (Shetty 2002). Per-capita consumption of edible oils, vegetables, fruits, milk, meat, fish, eggs, and sugar have increased substantially. Consumption of traditional coarse cereals and pulses (legumes) has declined despite the traditional importance of these items as sources of vegetable protein. Further, overall calorie consumption is decreasing in both urban and rural regions despite increasing incomes, a confusing paradox dubbed the “calorie consumption puzzle” that is likely due to reduced energy requirements (Basu & Basole 2013).

While there may be some nutritional benefits to dietary changes associated with the nutrition transition, there remain some notable deficiencies and concerning trends. First while vegetable consumption is increasing, average intake is still well below the recommended dietary allowance (RDA). Low vegetable and pulse consumption can lead to deficiencies in important micronutrients, such as iron, vitamin A, vitamin C, riboflavin, and calcium (Andersen et al. 2002; Toteja et al. 2002). In addition, low vegetable, whole grain, and pulse consumption may lead to insufficient fiber intake (Rema & Vasanthamani 2011). Low fiber intake is particularly concerning for non-communicable diseases (NCDs), and as mentioned above, has been proven to increase risk of obesity (Liu et al. 2003), diabetes (Radhika et al. 2009), and cardiovascular disease (Mozaffarian et al. 2003).

Second, consumption of both animal and vegetable fats has increased (Kumar & Dev 2007; Shetty 2002). The effect of this trend on epidemiology of NCDs is unclear. Most population health studies in India examine the effects of *total* fat intake, and thus fail to account for the diversity of fat and oil products consumed in India. There is some evidence to suggest that consumption of monounsaturated and polyunsaturated fats is decreasing, while consumption of saturated and trans-fats is increasing (Misra et al. 2011b). If true, this trend may exacerbate the obesity and diabetes epidemics (as described in Chapter 3). Further India-specific data are needed to confirm the health impacts of different types of fats and oils, and to elucidate the changing consumption patterns of different fats.

Another notable trend is shifting patterns in sugar and grain consumption. While sugar intake from traditional sources (e.g. cane sugar, honey, and *jaggery*) have been declining, and average intakes of sugar remain below recommended dietary allowances by the National Institute of Nutrition (NIN 2009), the rapid rise in popularity of prepackaged sugar-containing products like sweetened beverages and snacks may be concerning (Vepa 2004). Some research shows that sugar intake is higher amongst young populations (Tiwari & Sankhala 2007) and urban residents (Bowen et al. 2011). However, sugar intake data must be approached cautiously, as it is prone to reporting bias due to the "hidden" presence of sugar in foods such as tea, bakery items, and *mukhwas* (a traditional mixture of sweetened spices consumed to "sweeten the mouth" after meals), making it difficult to ascertain accurate trends (Gulati & Misra 2014). Nevertheless, the health effects of excess sugar consumption are well known and include increased risk of obesity, hypertension, kidney disease, type 2 diabetes, and cardiovascular disease (Malik et al. 2010; Vermunt et al. 2003). Advances in food processing technology and efforts to increase food storability has driven the increased availability and consumption of refined grains such as polished white rice and enriched white flour (Radhika et al. 2009). The refining process removes the grain husk, which contains micronutrients and dietary fibre, thus drastically increasing the digestibility and glycemic index of the grain (Slavin 2003). Research from USA (Liu 2002), Europe (McKeown et al. 2002), and more recently south India (Radhika et al. 2009) have linked refined grain intake with increased risk of obesity and the metabolic syndrome, as well as numerous cardiovascular disease risk factors.

There is a need for more detailed data to fully understand the historic and current food consumption of populations in India and how dietary change may be contributing to risk of NCDs and other nutrition-related ailments. Of particular concern is the rise of processed foods, which have been largely ignored by National Nutrition Monitoring Board and National Health and Family Survey data collecting methods. While consumption data for these foods are sparse, the growing economic influence of the food-processing sector suggests that processed foods are increasingly popular (Pingali and Khwaja 2004). Such trends are indicative of shifting food consumption patterns *within* food groups (e.g., from traditional to refined cereals, or from cane sugar- and *jaggery*-sweetened desserts to those sweetened with high fructose corn syrup) that may be overlooked by aggregate food data.

2.4 Relevant policy/economic/social processes driving the nutrition transition

Factors influencing and driving the nutrition transition in India are varied, and will be covered in detail in Chapter 7. Broadly, four primary processes influence physical activity and food consumption patterns: (1) agricultural changes; (2) government schemes; (3) open market forces, and (4) socio-cultural factors.

First, agricultural patterns in India have shifted over the past decades in ways that closely match food consumption trends. Diversification of agriculture away from cereals has occurred in all states. Production of cereals has declined by 50-80% in most states, in favour of fruit, vegetable, and livestock production (Binswanger-Mkhize & D'souza 2015; Birthal et al. 2011). This trend is reflective of increased commercial production, and may affect local availability in two primary (and opposing) ways. On one hand, improved transport and market infrastructure, as well as monetization of traditional crops, may incentivize food export from agricultural areas to urban areas or internationally, thus reducing the availability of local produce and forcing rural populations to depend increasingly on food purchased from markets, shops, and restaurants (Binswanger-Mkhize & D'souza 2015). On the other hand, improved crop diversity may result in improved dietary diversity among farmers, labourers, and the local rural population (Chapter 7).

Second, government schemes have become increasingly dominant in shaping food availability and accessibility. The most influential schemes are the Public Distribution System (PDS) and the Midday Meal Scheme (MMS), both of which predate but are currently mandated by the 2013 National Food Security Act (NFSA). The PDS distributes food grain (primarily wheat and rice), cooking oil, kerosene, and sugar at below-market prices (sometimes free of cost) to below poverty line families through hundreds of thousands of Fair Price Shops (FPSs) throughout the country (Radhakrishna et al. 1997). The MMS was developed and rolled out nationally in 2001 with the intention of providing nutritious meals free of charge to children for their first 10 years of public school. While the MMS has several proponents (e.g. Dreze & Goyal 2003), common criticisms include corruption, unhygenic food preparation, and failure to provide a balanced nutritional meal, instead promoting meals high in refined carbohydrates and low in protein (Ministry of Human Resource Development 2015). Indeed, one study audited 2102 schools and found that 89% failed to meet the mandated nutrition standard (ibid). Both the PDS and the MMS act as implicit income transfers and aim to improve under-nutrition and malnutrition, but unintended consequences may include promotion of refined grain, sugar, and oil consumption, with potential effects on risk of NCDs like obesity and diabetes (Khera 2011a; Thow et al. 2016).

Third, the impact of market forces on food and lifestyle changes are likely substantial. India is developing rapidly, and its economy has shifted from an agriculture-based economy to a services, manufacturing, and technology-based economy in the past 35 years (Planning Commission 2015). Incomes have improved in most sectors of Indian society, thus increasing purchasing power, which contributes to improved dietary diversity (Shetty 2002). Increased mechanization of agriculture has reduced the burden of labour on individual landholders and hired labourers, which has likely impacted physical activity patterns in rural regions. Meanwhile, growing urban economies drive rural-to-urban migration (either permanent or temporary), which ultimately impacts individual food and lifestyle patterns, both through increased incomes and urban assimilation (Ebrahim et al. 2010). Globalization and liberalization of food markets since the 1990s have provided opportunities for multinational and national food corporations to infiltrate urban and rural areas, increasing the availability of processed packaged foods and fast foods (Vepa 2004). This change has been pejoratively termed “Coca-Colonization”, and is likely contributing to shifting food consumption patterns in both rural and urban regions of India (Zimmet 2000).

Finally, India’s socio-cultural environment mediates the effects of the nutrition transition. The socio-cultural environment encompasses broad and ever-changing factors such as food preferences, body size preferences, religious preferences and restrictions, and cultural constructs and stigmas relating to exercise, fast foods, and sugar. Gender dynamics and discrimination, both within and outside the household, may influence access to food, stigmas regarding body size, and physical activity habits, thus influencing the relative health of women and men (Barcellos, Carvalho, & Lleras-Muney 2014). Food preferences influence food choice and consumption, and are dependent on habit formation and convenience (Herforth & Ahmed 2015). In rural India, the socio-cultural environment is evolving due to a variety of factors. For example, aggressive advertising campaigns by corporate food agencies (e.g. Coca-Cola, PepsiCo, and McDonalds) aimed at increasing the desirability of processed foods have been widely successful, perhaps in part due to the convenience of these foods and the opportunity costs associated with food preparation (Afridi et al. 2012). Simultaneously, public health education efforts aimed at educating the public about obesity and diabetes have been fractured and unsubstantial (Siegel, Venkat Narayan, & Kinra 2008). Gender, caste, and religion dynamics may also be shifting as India develops both economically and culturally (Gupta & Yasudian 2006). Chapter 7 has an in-depth discussion of these factors.

All of these processes - agricultural patterns, government schemes, market forces, and socio-cultural environments - are interconnected, complex, and multifactorial. Researching and elucidating the individual effects of policy and economic processes is a difficult task; nevertheless, it is crucial to further our understanding of the type 2 diabetes epidemic, and ultimately act to address this severe public health emergency.

2.5 Addressing the diabetes epidemic in India

Although there has been some action to address the diabetes epidemic in India, progress has been slow and fragmented (Siegel, Venkat Narayan, & Kinra 2008). As in other low- and middle-income countries, public health advocacy has focused primarily on communicable diseases, nutritional deficiencies, and population stabilization (Reddy et al. 2005). The widely held view that diabetes mainly affected the rich, as well as limited health budgets, prevented public sector resources from flowing into prevention and control. Although several nutrition programs exist that aim to address nutritional deficiencies (e.g. PDS and MMS), they do not incorporate into their mandate the need to prevent chronic diseases (ibid).

In 2005, the Ministry of Health and Family Welfare (MHFW) spearheaded a national consultation to identify action pathways and partnerships for the implementation of the WHO Global Strategy on Diet, Physical Activity, and Health. In May 2008, at the 61st World Health Assembly, the Indian Health Minister endorsed the Action Plan for the Global Strategy for the

Prevention and Control of Non-communicable Diseases. Consequently, the Government of India initiated the integrated National Program for Prevention and Control of Diabetes, Cardiovascular Disease, and Stroke (NPCDCS). The program focuses on strengthening infrastructure (including human resources), health promotion and prevention, early diagnosis and management, and better integration of healthcare providers (MHFW 2010). The 2012 Department of Health Research Planning Commission's "XII Five-Year Plan Document (2012-2017)" recognized obesity and diabetes as severe public health challenges and proposed several interventions, including strengthening the National Rural Health Mission (NRHM) mandate to include action on NCDS, as well as education programming, expanded screening, and better tertiary care for diabetes complications (Planning Commission 2011). Some beneficial programs have been implemented recently; for example, state-led surveillance programs to obtain accurate prevalence data of NCDs and associated risk factors (Ministry of Health and Family Welfare 2009). Most recently, in January 2015, India became the first country to adopt WHO's Global Monitoring Framework on Non-communicable Diseases, setting the goal of reducing premature deaths due to NCDs by 25% before 2025. Included in that framework was also a goal to "halt the rise of obesity and diabetes" (WHO 2013; WHO 2015).

However, beyond recognizing NCDs as a problem, government agencies have been slow to implement successful programs to prevent and combat the growing problem of diabetes in India (Khandelwal & Reddy 2013). While the NRHM has adopted NCDs as a priority, studies from rural India suggest that large-scale screening and community health programs are nonexistent and rural healthcare centers lack resources to provide adequate care for patients with diabetes and often suffer from severe medication shortages, forcing patients to pay out-of-pocket (Little et al. 2016a; Raut-Marathe et al. 2015). While efforts to control tobacco (outlined in the Tobacco Control Act of 2003) have been somewhat successful, tobacco consumption is still very high, particularly in rural areas (Mishra et al. 2012). In addition, opportunities for preventing diabetes by promoting exercise, incorporating healthy foods into government nutrition schemes (Khera 2011b), junk food and beverage regulations (e.g. progressive labeling), health promotion campaigns (Deepa et al. 2005), and workplace and school interventions (Reddy et al. 2006) have been overlooked (Khandelwal & Reddy 2013). Many experts agree that a comprehensive and effective strategy for preventing and managing the growing burden of diabetes in India is needed (Prabhakaran et al. 2005; Siegel, Narayan, & Kinra 2008).

2.6 Diabetes in context: The double burden of malnutrition in India

India's nutrition transition (and the processes behind it), despite driving up prevalence of diabetes, has failed to adequately address problems of poverty, poor environmental sanitation, and under-nutrition among substantial portions of the population. This has led to a 'double burden' of malnutrition in India, in which epidemics of diabetes and obesity are occurring simultaneously with persistent conditions of poverty-associated health outcomes such as underweight, under-nutrition, and associated nutritional disorders like anemia (Jones et al. 2016). The double burden of malnutrition (which has also been called the 'nutrition paradox') is common in LMICs undergoing the nutrition transition, and in addition to India (Jones et al. 2016), has been reported in Brazil (Caballero 2005), Vietnam (Khan & Hoi 2008), China, (Doak et al. 2005), Russia (ibid), Kyrgyzstan (ibid), and Indonesia (ibid). In India, despite high rates of overweight and obesity (15-20% in adults), over one-third of women of childbearing age (15-49) are underweight (36%) (Jones et al. 2016). However, the nutritional double burden is not limited to the co-occurrence of underweight and obesity at the national level; in fact, it is increasingly common that markers and complications of both under- and over-nutrition occur in the same region, household, and occasionally in the same person. For example, household double burden may occur when children are underweight or stunted despite overweight parents or family members (Caballero 2005). Similarly, individuals who are malnourished and experiencing micronutrient deficiencies and associated disorders (e.g. anemia) may simultaneously consume excess dietary energy, leading to obesity and associated cardio-metabolic disorders (e.g. CVD and diabetes). Jones and colleagues (2016) conducted the only study to date on individual double burden in India, in which they analyzed data from the Andhra Pradesh Children and Parents Study (APCAPS), and found that prevalence of the double burden (defined as simultaneous existence of anemia and obesity and/or metabolic syndrome) in semi-rural Andhra Pradesh was 1.2% for men and 9% for women. However, data collection methods of APCAPS may have underestimated the prevalence of the double burden, particularly since they used fasting plasma glucose to diagnose diabetes, a protocol that is known to have low sensitivity (Mostafa et al. 2011).

The existence of a nutritional double burden at the household or individual level indicates that quantity of food may not be the problem, but that families and individuals lack sufficient access to *nutritious* food. This leads to household double burden when adults consume enough energy to gain weight, but a child does not consume enough nutrients to grow adequately (Dieffenbach & Stein 2012). Similarly, it may lead to individual double burden when a person consumes enough energy to gain weight, but not enough nutrients to prevent nutrient deficiency and related disorders. As mentioned above, children with stunted growth are more prone to obesity later in life, which may exacerbate the double burden. Moreover, as early as the mid-1990s, Mohan and colleagues noted the co-occurrence of underweight and diabetes, which they refer to as “lean diabetes”, and which accounted for 3.5% of all diabetes patients in a study conducted at Dr. Mohan’s Diabetes Specialties Centre in urban Chennai (Mohan et al. 1997). This co-morbidity is confusing and understudied, but appears more common in south Asian contexts (George, Jacob, & Fogelfeld 2015; Hussain et al. 2007).

Regardless of its causes, the nutritional double burden poses significant challenges to Indian health and economic policy and programs, particularly as it becomes increasingly prevalent due to India’s continued socioeconomic development (Jones et al. 2016). Indian health care facilities are already overwhelmed and often lack resources and personnel to adequately provide public healthcare, so future health projections do not bode well.

2.7 Research motivation, and summary

Despite growing attention from researchers, type 2 diabetes in India is poorly understood. Prevalence data on diabetes and the double burden of disease are needed to describe the extent of the issue. In addition, it is important to explore associations between health outcomes and different exposure variables to gain a grasp on both proximate and distal risk factors driving the diabetes epidemic and persistent malnutrition. Finally, a comprehensive understanding of the conditions and experiences faced by people with diabetes is necessary to recognize where gaps exist in caring for diabetes patients. This thesis contributes to the growing body of knowledge on diabetes and the double burden of disease in rural India.

2.7.1 Research motivation

My interest in global health, nutrition, and epidemiology of type 2 diabetes began in 2009 during a semester abroad program in Antigua, Guatemala. During this time, I sought guidance from Dr. Sally Humphries, who graciously agreed to supervise an independent research project. I partnered with two non-governmental organizations (NGOs) in two different rural communities to conduct interviews with individuals living with type 2 diabetes. The people I spoke with, the manuscript that I wrote, and the discussions I had with NGO representatives and Dr. Humphries confirmed that our topic was important. That research was engaging, rewarding, and formative, and it was also my first exposure to the significance of global health and epidemiology research. I was impressed with (and grateful for) Dr. Humphries' guidance; and while I cannot say if she felt the same, she approached me in 2011 to discuss my potential involvement as a graduate student with a large multi-disciplinary research project that had recently recruited her as a gender specialist. After initial trepidation, I applied for and accepted a position as a PhD student in the collaborative Population Medicine and International Development program at the University of Guelph, under the co-supervision of Drs. Sally Humphries and Cate Dewey, with the intention of working with partners in India to investigate the nutrition transition and type 2 diabetes.

2.7.2 Description of studies included in this thesis

The primary research included in this thesis is a component of a large, interdisciplinary international development project, entitled "Revalorizing Small Millets in the Rainfed Regions of South India" (RESMISA). RESMISA was funded through the Canadian International Food Security Research Fund by the International Development Research Centre (IDRC) and the Department of Foreign Affairs, Trade, and Development (DFATD (formerly the Canadian International Development Agency and now Global Affairs Canada) from 2011-2014.

The overarching objective of RESMISA was to promote the cultivation and consumption of nutritious small millets, pulses, and oil seeds to enhance food and nutritional security. Cultivation of small millets has been largely overlooked in Indian agricultural policy and innovation in favour of rice, wheat, and other commercial crops (Deaton & Dreze 2009;

Kumar & Dey 2007). RESMISA aimed to promote small millets by conducting innovative research on variety resilience, post-harvest technology, and value-added product development. The project also hoped to elucidate socio-economic, health, and political barriers and opportunities of smallholder farmers and families in the research sites.

RESMISA activities were implemented in six sites in four Indian states (Jharkhand, Odisha, Andhra Pradesh, and Tamil Nadu), as well as one site in Sri Lanka and two sites in Nepal (Figure 2.1). The sites were selected due to their location in rainfed regions and high prevalence of poverty and food and nutritional insecurity. All sites were geographically remote and included a diversity of agro-ecological, political, economic, and sociocultural environments. Anchetty was selected as one of the research sites in Tamil Nadu (TN). This was also the project site that I selected for my research activities (Figure 2.1).

2.7.3 Research location

It is important to note that Anchetty is the general name for the research site within the RESMISA project, but it is also the name of the largest *panchayat* (township) in the region, as well as the village that serves as the administrative center of that *panchayat.* Thirteen other villages are located within the Anchetty *panchayat.* The research site also included three other *panchayats* that bordered Anchetty, namely Madakkal *panchayat*, Thagatti *panchayat*, and Urigam *panchayat*. All four *panchayats* are located in the Krishnagiri district, which is among the poorest districts in Tamil Nadu, with the lowest life expectancy, one of the lowest Gross Domestic Products, and the second-lowest literacy rate in the state (Srivastava, Shanmugam, & Bhujanga Rao 2010). Within the research site, the prevalence of poverty (36%) and illiteracy (48.3%) are even higher than district averages (Karthikeyan et al. 2012).

There is a history of NGO interventions in the study region. The Development for Humane Action (DHAN) Foundation has operated a regional office in Anchetty since 2006, and has conducted a variety of agricultural research, intervention, and promotion activities. DHAN Foundation was an integral partner in the RESMISA project, and several project sites in India (including Anchetty) were selected due to DHAN Foundation's existing presence. DHAN supported several international students during their research in Anchetty, myself included.

2.7.3.1 Notable characteristics of research site

The research site, comprised of all four aforementioned *panchayats,* is located in the Melagiri Hills of the Eastern Ghats mountain range, in northwest Tamil Nadu. The region borders Karnataka, and as such, it is a multilingual region, with Tamil (the state language of TN) and Kannada (the state language of Karnataka) being the most common languages. The region is primarily agricultural, with approximately 79% of households depending on crop production, livestock production, or agricultural labour as their primary livelihood (Chapter 7). Agriculture is mostly rain-fed, meaning landholders depend on natural precipitation rather than irrigation, and so there is only one growing season. Anchetty *panchayat* is relatively better serviced than the other *panchayats*, with access to public transportation and easy availability of public services such as schools and health care. There were several primary schools, one secondary school, four private healthcare clinics, and one public healthcare facility in Anchetty *panchayat*, while none of the other *panchayats* had a health care facility. All *panchayats* were within 40 kilometers of the large urban center of Hosur, and within 120 kilometers of the megacity of Bengaluru. Many residents in the project site participated in temporary labour migration between their home villages and these urban regions (Dodd et al. 2016).

While India's caste system is waning, rural Indian society is still divided along caste groupings (Vaid 2014), and the Anchetty region is no different. In the project site, caste was divided into five broad categories: Scheduled Castes (SC), Scheduled Tribes (ST), Other Backward Castes (OBC), Most Backward Castes (MBC), and Brahmin (Higher Caste). Importantly, entitlements through government schemes are often determined based on caste, with SC and ST eligible for greater benefits than OBC and MBC, and Brahmin Castes eligible for the fewest entitlements (Department of Backward Classes and Most Backward Classes and Minority Welfare 2015).

2.7.2 Description of research activities

Prior to initiating research activities in the Anchetty region, I developed and defended a proposal that described the intended research, which included three components: (1) convenience interviews to explore local experiences and conceptualizationso of food, nutrition, health, and illness, as well as to familiarize myself with the sociocultural environment, population characteristics, and research needs; (2) a qualitative examination on the perceptions and experiences of individuals living with diabetes; and (3) a cross-sectional epidemiology study to determine the prevalence and risk factors associated with diabetes. Initially, I received ethics approval through the University of Guelph Research Ethics Board for components (1) and (2). I traveled to Anchetty in November 2012 with the intention of staying for 6 months. Prior to initiating research, I sought and obtained information and permission from local health authorities, *panchayat* political authorities, and DHAN Foundation leaders.

Initial research activities were conducted in December 2012 – January 2013, and consisted of 61 semi-structured interviews in 17 villages in the *panchayats* of Anchetty (8 villages, 28 interviews), Thagatti (4 villages, 13 interviews), Madakkal (3 villages, 17 interviews), and Urigam (2 villages, 4 interviews). These interviews were intended to fulfill four primary objectives. First, I aimed to determine the extent to which diabetes was perceived as a problem and perceptions surrounding the disease, and gain a general understanding of health, and livelihoods in the research site. Second, I aimed to identify a number of perceived characteristics of the food environment that influence individuals' food choices and consumption. Third, I hoped to assess the plausibility of conducting the two large research projects (components 2 and 3 above) that would ultimately comprise the bulk of the research for this thesis. Fourth and finally, I wanted to familiarize myself with the project site, earn the respect of local communities, and gain an understanding of the rhythms of rural livelihoods, my positionality as a foreign male researcher, and local understandings and vocabulary for the topics of my research. This scoping research proved crucial for determining how to effectively and respectfully conduct future research in the project site. The 61 interviews were transcribed and immediately analyzed using a thematic analysis (Vaismoradi et al. 2013). Select data from this study are presented in Chapter 7. This study proved immensely useful for informing subsequent research activities.

Following this initial study, I decided to focus future research primarily on Anchetty and Madakkal *panchayats*, largely due to logistical convenience and data saturation concerns. In February 2013-March 2013, I conducted a second study, during which I recruited a convenience sample of 54 individuals with diagnosed diabetes and conducted (1) in-depth interviews; (2) a 'structured vignette' validation activity with a subset of ten participants; and (3) gender-segregated focus groups with a subset of eight participants (four men and four women). The results of this study are presented in Chapter 5.

During these initial 6 months in the research site, I understood that meaningful community-driven research was impossible without strong research partners. While DHAN's assistance was valuable in terms of logistics and local knowledge, their research interests were somewhat detached from my own. Whereas DHAN was primarily focused on small millet production and consumption, I was interested in broader concepts of food security, nutrition, and nutrition-related diseases, and in particular, obesity and diabetes. Consequently, I sought other partnerships with researchers and organizations whose mandates aligned more closely with my own. This led me to approach Dr. Sudha Vasudevan, of the Madras Diabetes Research Foundation (MDRF), which is housed in Dr. Mohan's Diabetes Specialties Center in Chennai, Tamil Nadu. MDRF is one of the most prolific and influential NCD medical and epidemiological research groups in India, having developed dozens of research tools and published over 1000 manuscripts on diabetes (for a full list see Madras Diabetes Research Foundation 2016). Over the course of several meetings with Dr. Vasudevan, we agreed to form a partnership that would permit me to use a food frequency questionnaire (FFQ) that was previously validated for Tamil Nadu (Radhika et al. 2009). The FFQ was a questionnaire paired to a computer data entry and analysis program that would provide detailed dietary intake information for each participant in future studies, including macro- and micronutrient consumption.

After returning to Canada to plan the next phase of research at the project site, I amended my ethics certificate and received approval from the University of Guelph REB for the third and final research component, which included approval to collect biological (i.e. blood) samples (certificate number 12MY019). I once again traveled to Anchetty from November 2013 – March 2014 with a plan to conduct a large-scale cross-sectional study. After receiving written permission from the High Commission of India, district-level officials, the district Medical Officer, the *Taluk* (sub-district) police chief, and several other authorities, I hired five research assistants (including two nutritionists, one medical doctor, and one registered nurse), conducted three days training with them at the MDRF facility in Chennai, and initiated the study. We systematically randomly sampled one individual from each of 753 randomly selected households in 17 villages in Anchetty and Madakkal *panchayats* for participation (Figure 2.2). With all participants, we conducted an oral glucose tolerance test, anthropometric measurements, a capillary hemoglobin test, and blood pressure measurements. We collected information on location and descriptive characteristics, household wealth, physical activity patterns (using WHO's global physical activity questionnaire), knowledge of diabetes (using MDRF's diabetes awareness tool), and dietary intake (using the MDRF food frequency questionnaire). Data resulting from this study are presented in Chapters 3, 4, 6, and 7.

2.7.3 Research framework

A mixed methods study design was used, whereby qualitative data were used as both an exploratory and explanatory tool (Figure 2.3). Qualitative methods (components 1 and 2 above) were first used to gather data about perceptions and experiences and generate hypotheses for further exploration during the quantitative methods (component 3 above). Quantitative methods were then used to test hypotheses generated during the exploratory qualitative activities, and also to generate hypotheses about distal socio-economic-political factors associated with health outcomes. Following this, we re-visited qualitative data to explain and triangulate phenomena and associations from the quantitative study, and to improve the cultural sensitivity of policy and public health recommendations. While this framework was used to inform research activities, chapters included in this thesis are primarily quantitative (e.g. Chapters 3, 4, and 6), primarily qualitative (e.g. Chapter 5), and mixed methods (e.g. Chapter 6).

2.7.4 Research rationale and objectives

Despite growing attention from researchers, type 2 diabetes in rural India is poorly understood. Prevalence data on diabetes and on the double burden of malnutrition are needed to describe the extent of these issues. In addition, it is important to explore associations between health outcomes and different exposure variables to determine potential proximate and distal risk factors driving the diabetes epidemic and persistent malnutrition. Finally, a comprehensive understanding of the conditions and experiences faced by people with diabetes is necessary to recognize where gaps exist in caring for patients with diabetes. Drawing on eleven months of data collection in southern India using qualitative and quantitative tools, this thesis aims to provide a comprehensive analysis of the pertinent public health problem of type 2 diabetes in the *panchayats* of Anchetty and Madakkal, and position this issue within the broader socioeconomic, political, and development landscape of rural India.

The key objectives of the research are as follows:

1) **Identify the prevalence of obesity and type 2 diabetes** in Anchetty and Madakkal *panchayats*, Krishnagiri District, Tamil Nadu, India**.**
2) **Determine the risk factors associated with obesity** in Anchetty and Madakkal *panchayats*, Krishnagiri District, Tamil Nadu, India.
3) **Determine the risk factors associated with newly-diagnosed type 2 diabetes** in Anchetty and Madakkal *panchayats*, Krishnagiri District, Tamil Nadu, India.

4) **Explore perceptions and experiences of individuals with type 2 diabetes, including explanatory models, barriers to management, and illness narratives** in Anchetty and Madakkal *panchayats*, Krishnagiri District, Tamil Nadu, India.

5) **Elucidate the double burden of malnutrition (under- and over-nutrition), including regional prevalence, as well as risk factors associated with individual-level double burden of malnutrition**, in Anchetty and Madakkal *panchayats*, Krishnagiri District, Tamil Nadu, India.

6) **Analyze the food environment of rural Tamil Nadu, including availability, affordability, desirability, and convenience of food, and determine how the food environment contributes to food choice and consumption patterns.**

2.7.5 Thesis organization

This thesis follows a manuscript style format and includes papers that have been published (Chapters 3-5) and others that are currently under review or in preparation (Chapters 6 & 7). This thesis consists of eight chapters, including the two introductory chapters:

Chapter 1: Type 2 diabetes: A global health emergency

This chapter provides a literature review on the current global epidemic of diabetes, including a brief description of pathophysiology of the disease, known risk factors, diagnostic testing, and global epidemiology.

Chapter 2: Type 2 diabetes in India: burden, etiology, and context

This chapter provides a literature review on the epidemiology and etiology of diabetes in India, including a discussion of the unique etiology of the Indian epidemic. I also introduce the concept of the double burden of disease and describe the need for further research in India.

Chapter 3: Prevalence and factors associated with BMI, underweight, and obesity among adults in a region of rural south India: A cross-sectional study

This chapter presents the findings of a cross-sectional study on the prevalence of obesity and the risk factors that were associated with overweight and obesity in the study site.

Chapter 4: Prevalence and risk factors associated with glucose tolerance, pre-diabetes, and diabetes in a rural community of south India: A cross-sectional study

This chapter presents the findings of a cross-sectional study on the prevalence of impaired glucose tolerance, impaired fasting glucose, and type 2 diabetes. Risk factors are presented to elucidate the etiology of diabetes in the research site.

Chapter 5: Decoding the diabetes epidemic in rural India

This chapter presents the findings of a qualitative study on disease explanatory models, illness narratives, and barriers to management among a group of 54 patients with diagnosed diabetes.

Chapter 6: The 'double burden' of under- and over-nutrition in a rural population in southern India

This chapter presents the findings of a cross-sectional study investigating the prevalence and risk factors associated with the double burden of nutrition, characterized as the co-morbidity of anemia and obesity and/or co-morbidity of anemia and diabetes.

Chapter 7: An analysis of the food environment and its impact on food choice and consumption in rural south India

This chapter employs a food environment framework to investigate the distal factors associated with the double burden of disease in Tamil Nadu. We identify characteristics of the food environment that affect the availability, affordability, desirability, and convenience of foods, then examine associations between these characteristics and food consumption.

Chapter 8: Summary discussion, recommendations, and conclusion

This chapter brings together the findings of the literature review and original research presented in the thesis, and presents recommendations for policy, practice, and future research efforts.

REFERENCES

Abate, N., Chandalia, M., Snell, P. G., & Grundy, S. M. (2004). Adipose tissue metabolites and insulin resistance in nondiabetic Asian Indian men. *The Journal of Clinical Endocrinology & Metabolism*, *89*(6), 2750-2755.

Abdallah, S., Singer, P. A., Persad, D. L., Pramming, S. K., Matthews, D. R., et al. (2007). Grand challenges in chronic non-communicable diseases. *Nature*, 450(7169):, 494-496.

Abegunde, D. O., Mathers, C. D., Adam, T., Ortegon, M., & Strong, K. (2007). The burden and costs of chronic diseases in low-income and middle-income countries. *The Lancet*, *370*(9603), 1929-1938.

Afridi, F., Mukhopadhyay, A., & Sahoo, S. (2012). Female labour force participation and child education in India: the effect of the national rural employment guarantee scheme.

Andersen, L. T., Thilsted, S. H., Nielsen, B. B., & Rangasamy, S. (2003). Food and nutrient intakes among pregnant women in rural Tamil Nadu, South India. *Public Health Nutrition*, *6*(02), 131-137.

Anjana, R. M., Pradeepa, R., Deepa, M., Datta, M., Sudha, V., et al. (2011). Prevalence of diabetes and prediabetes (impaired fasting glucose and/or impaired glucose tolerance) in urban and rural India: Phase I results of the Indian Council of Medical Research–INdia DIABetes (ICMR–INDIAB) study. *Diabetologia*, *54*(12), 3022-3027.

Anjana, R. M., Pradeepa, R., Das, A. K., Deepa, M., Bhansali, et al. (2014). Physical activity and inactivity patterns in India–results from the ICMR-INDIAB study (Phase-1)[ICMR-INDIAB-5]. *International Journal of Behavioral Nutrition and Physical Activity*, *11*(1), 26.

Balagopal, P., Kamalamma, N., Patel, T. G., & Misra, R. (2008). A community-based diabetes prevention and management education program in a rural village in India. *Diabetes Care*, *31*(6), 1097-1104.

Barcellos, S. H., Carvalho, L. S., & Lleras-Muney, A. (2014). Child gender and parental investments in India: are boys and girls treated differently? *American Economic Journal: Applied Economics*, *6*(1), 157-189.

Basu, D., & Basole, A. (2012). *The calorie consumption puzzle in India: An empirical investigation* (No. 2012-07). Working Paper, University of Massachusetts, Department of Economics.

Bhattacharya, M. (2015). A historical exploration of Indian diets and a possible link to insulin resistance syndrome. *Appetite*, *95*, 421-454.

Bharati, D. R., Pal, R., Rekha, R., & Yamuna, T. V. (2011). Evaluation of the burden of type 2 diabetes mellitus in population of Puducherry, South India. *Diabetes & Metabolic Syndrome: Clinical Research & Reviews*, *5*(1), 12-16.

Bhatia, V., Arya, V., Dabadghao, P., Balasubramanian, K., Sharma, K., Verghese, N., & Bhatia, E. (2004). Etiology and outcome of childhood and adolescent diabetes mellitus in North India. *Journal of Pediatric Endocrinology and Metabolism, 17*, 993-1000.

Birthal, P. S., Singh, H., & Kumar, S. (2011). Agriculture, economic growth and regional disparities in India. *Journal of International Development*, *23*(1), 119-131.

Binswanger-Mkhize, H. P., & D'souza, A. (2015). Structural Change and Agricultural Performance at the State Level in India: 1980-2010. *Agricultural Economics Research Review*, *28*(1).

Bowen, L., Ebrahim, S., De Stavola, B., Ness, A., Kinra, S., et al. (2011). Dietary intake and rural-urban migration in India: a cross-sectional study. *PloS one*, *6*(6), e14822.

Caballero, B. (2005). A nutrition paradox—underweight and obesity in developing countries. *New England Journal of Medicine*, *352*(15), 1514-1516.

Census India. (2011). Rural Urban Distribution of Population. Available at: http://censusindia.gov.in/2011-prov-results/paper2/data_files/india/Rural_Urban_2011.pdf. Accessed 5 Feb 2017.

Chambers, J. C., & Kooner, J. S. (2002). Diabetes, insulin resistance and vascular disease among Indian Asians and Europeans. In *Seminars in vascular medicine* (Vol. 2, No. 02, pp. 199-214). New York, NY.

Chandalia, M., Abate, N., Garg, A., Stray-Gundersen, J., & Grundy, S. M. (1999). Relationship between Generalized and Upper Body Obesity to Insulin Resistance in Asian Indian Men 1. *The Journal of Clinical Endocrinology & Metabolism*, *84*(7), 2329-2335.

Chow, C., Cardona, M., Raju, P. K., Iyengar, S., Sukumar, A., et al. (2007). Cardiovascular disease and risk factors among 345 adults in rural India—the Andhra Pradesh Rural Health Initiative. *International Journal of Cardiology*, *116*(2), 180-185.

Deaton, A., & Drèze, J. (2009). Food and nutrition in India: facts and interpretations. *Economic and Political Weekly*, 42-65.

Deepa, M., Deepa, R., Shanthirani, C. S., Manjula, D., Unwin, N. C., Kapur, A., & Mohan, V. (2005). Awareness and knowledge of diabetes in Chennai--the Chennai Urban Rural Epidemiology Study [CURES-9]. *The Journal of the Association of Physicians of India*, *53*(4), 283-287.

Deepa, R., Sandeep, S., & Mohan, V. (2006). Abdominal obesity, visceral fat and Type 2 diabetes-"Asian Indian Phenotype". In: Mohan, V & Rao, G. H. (eds). Type 2 Diabetes in South Asia: Epidemiology, Risk Factors, and Prevention. Jaypee Medical Publishers. New Delhi: India, pp. 138-152.

Department of Backwards Classes and Most Backwards Classes and Minority Welfare. (2015). Available at: http://www.bcmbcmw.tn.gov.in/bclist.htm. Accessed 18 Jan 2016.

Department of Backwards Classes and Most Backwards Classes and Minority Welfare. (2015). Available at: http://www.bcmbcmw.tn.gov.in/bclist.htm. Accessed 18 Jan 2016.

Dieffenbach, S., & Stein, A. D. (2012). Stunted child/overweight mother pairs represent a statistical artifact, not a distinct entity. *The Journal of Nutrition*, *142*(4), 771-773.

Dinneen, S. F., & Rizza, R. A. (2007). Progression from newly acquired impaired fasting glucose to type 2 diabetes. *Diabetes Care*, *30*(7), e79-e79.

Doak CM, Adair LS, Bentley M, Monteiro C, Popkin BM. (2005). The dual burden household and the nutrition transition paradox. *International Journal of Obesity and Related Metabolic Disorders*, 29, 129-36

Dodd, W., Humphries, S., Patel, K., Majowicz, S., & Dewey, C. (2016). Determinants of temporary labour migration in southern India. *Asian Population Studies*, *12*(3), 294-311.

Dreze, J., & Goyal, A. (2003). Future of mid-day meals. *Economic and Political Weekly*, 4673-4683.

Ebrahim, S., Kinra, S., Bowen, L., Andersen, E., Ben-Shlomo, Y., et al. (2010). The effect of rural-to-urban migration on obesity and diabetes in India: a cross-sectional study. *PLoS Med*, *7*(4), e1000268.

George, A. M., Jacob, A. G., & Fogelfeld, L. (2015). Lean diabetes mellitus: An emerging entity in the era of obesity. *World Journal of Diabetes*, *6*(4), 613.

Guariguata, L., Whiting, D. R., Hambleton, I., Beagley, J., Linnenkamp, U., & Shaw, J. E. (2014). Global estimates of diabetes prevalence for 2013 and projections for 2035. *Diabetes Research and Clinical Practice*, *103*(2), 137-149.

Gulati, S., & Misra, A. (2014). Sugar intake, obesity, and diabetes in India. *Nutrients*, *6*(12), 5955-5974.

Gupta, K., & Yesudian, P. P. (2006). Evidence of women's empowerment in India: A study of socio-spatial disparities. *GeoJournal*, *65*(4), 365-380.

Hussain, A., Vaaler, S., Sayeed, M. A., Mahtab, H., Ali, S. K., & Khan, A. A. (2007). Type 2 diabetes and impaired fasting blood glucose in rural Bangladesh: a population-based study. *The European Journal of Public Health*, *17*(3), 291-296.

Herforth, A., & Ahmed, S. (2015). The food environment, its effects on dietary consumption, and potential for measurement within agriculture-nutrition interventions. *Food Security*, *7*(3), 505-520.

International Diabetes Federation. (2014). IDF Diabetes Atlas, 6th ed. http://www.idf.org/sites/default/files/EN_6E_Atlas_Full_0.pdf. Accessed 23 May 2015.

Jones, A. D., Hayter, A. K., Baker, C. P., Prabhakaran, P., Gupta, V., et al. (2016). The co-occurrence of anemia and cardiometabolic disease risk demonstrates sex-specific sociodemographic patterning in an urbanizing rural region of southern India. *European Journal of Clinical Nutrition*, *70*(3), 364-372.

Joshi, S. R. (2003). Metabolic syndrome - Emerging clusters of the Indian phenotype. *Journal of the Association of Physicians of India*, *51*, 445-446.

Karthikeyan, M., Jena, D., Patel, K., Khadka, K., Devkota, R., Samaratunga, H., & Sakkari, K. (2012). Baseline Survey in Project Sites: A Report as a Part of 'Revalorizing Small Millets in the Rainfed Regions of South Asia (RESMISA)', India, Nepal, Sri Lanka and Canada: DHAN Foundation, Arthacharya Foundation, Local Initiatives for Biodiversity, Research and Development (LIBIRD) and Canadian Mennonite University.

King, H., Aubert, R. E., & Herman, W. H. (1998). Global burden of diabetes, 1995–2025: prevalence, numerical estimates, and projections. *Diabetes Care*, *21*(9), 1414-1431.

Khan, N. C., & Khoi, H. H. (2008). Double burden of malnutrition: the Vietnamese perspective. *Asia Pacific Journal of Clinical Nutrition*, *17*(S1), 116-118.

Khandelwal, S., & Reddy, K. S. (2013). Eliciting a policy response for the rising epidemic of overweight‐obesity in India. *Obesity Reviews*, *14*(S2), 114-125.

Khera, R. (2011a). Revival of the public distribution system: evidence and explanations. *Economic and Political Weekly*, *46*(44-45), 36-50.

Khera, R. (2011b). India's public distribution system: utilisation and impact. *Journal of Development Studies*, *47*(7), 1038-1060.

Kumar, P., & Dey, M. M. (2007). Long-term changes in Indian food basket and nutrition. *Economic and Political Weekly*, 3567-3572.

Lang, T., & Rayner, G. (2007). Overcoming policy cacophony on obesity: an ecological public health framework for policymakers. *Obesity Reviews*, *8*(s1), 165-181.

Laws, A., Jeppesen, J. L., Maheux, P. C., Schaaf, P., Chen, Y. D., & Reaven, G. M. (1994). Resistance to insulin-stimulated glucose uptake and dyslipidemia in Asian Indians. *Arteriosclerosis, Thrombosis, and Vascular Biology*, *14*(6), 917-922.

Lawton, J., Ahmad, N., Hanna, L., Douglas, M., & Hallowell, N. (2006). 'I can't do any serious exercise': barriers to physical activity amongst people of Pakistani and Indian origin with type 2 diabetes. *Health Education Research*, *21*(1), 43-54.

Little, M., Humphries, S., Patel, K., & Dewey, C. (2016a). Decoding the type 2 diabetes epidemic in rural India. *Medical Anthropology*, 1-15.

Little, M., Humphries, S., Patel, K., Dodd, W., & Dewey, C. (2016b). Factors associated with glucose tolerance, pre-diabetes, and type 2 diabetes in a rural community of south India: a cross-sectional study. *Diabetology & Metabolic Syndrome*, 8(1), 21.

Liu, S. (2002). Intake of refined carbohydrates and whole grain foods in relation to risk of type 2 diabetes mellitus and coronary heart disease. *Journal of the American College of Nutrition*, *21*(4), 298-306.

Madras Diabetes Research Foundation. 2016. Research Publications. Available at: http://www.mdrf.in/publications/current_year_pub.html. Accessed 3 February 2017.

Malik, V. S., Popkin, B. M., Bray, G. A., Després, J. P., Willett, W. C., & Hu, F. B. (2010). Sugar-sweetened beverages and risk of metabolic syndrome and type 2 diabetes a meta-analysis. *Diabetes Care*, *33*(11), 2477-2483.

McKeigue, P. M., Shah, B., & Marmot, M. G. (1991). Relation of central obesity and insulin resistance with high diabetes prevalence and cardiovascular risk in South Asians. *The Lancet*, *337*(8738), 382-386.

McKeown, N. M., Meigs, J. B., Liu, S., Wilson, P. W., & Jacques, P. F. (2002). Whole-grain intake is favorably associated with metabolic risk factors for type 2 diabetes and cardiovascular disease in the Framingham Offspring Study. *The American Journal of Clinical Nutrition*, *76*(2), 390-398.

Ministry of Health and Family Welfare. (2009). Integrated Disease Surveillance Report: Non-Communicable Disease Risk Factor Survey. Available at: http://www.icmr.nic.in/final/IDSP-NCD%20Reports/Phase-1%20States%20of%20India.pdf. Accessed 20 Jan 2017.

Ministry of Health and Family Welfare. (2010). National Programme for Prevention and Control of Diabetes Cardiovascular Disease and Stroke (NPCDCS) approved. Press Information Bureau: Delhi.

Ministry of Human Resource Development. (2015). Performance Audit of Mid Day Meal Scheme. Available at:

http://www.indiaenvironmentportal.org.in/files/file/performance%20audit%20of%20mid%20day%20meal%20scheme.pdf. Accessed 5 Feb 2017.

Mishra, G. A., Pimple, S. A., & Shastri, S. S. (2012). An overview of the tobacco problem in India. *Indian Journal of Medical and Paediatric Oncology, 33*(3), 139.

Misra, A., Pandey, R. M., Rama Devi, J., Sharma, R., Vikram, N. K., & Khanna, N. (2001). High prevalence of diabetes, obesity and dyslipidaemia in urban slum population in northern India. *International Journal of Obesity & Related Metabolic Disorders*, *25*(11).

Misra, A., & Vikram, N. K. (2002). Insulin resistance syndrome (metabolic syndrome) and Asian Indians. *Current Science, 83*(12), 1483-1496.

Misra, P., Upadhyay, R. P., Misra, A., & Anand, K. (2011a). A review of the epidemiology of diabetes in rural India. *Diabetes Research and Clinical Practice, 92*(3), 303-311.

Misra, A., Singhal, N., Sivakumar, B., Bhagat, N., Jaiswal, A., & Khurana, L. (2011b). Nutrition transition in India: Secular trends in dietary intake and their relationship to diet-related non-communicable diseases. *Journal of Diabetes, 3*(4), 278-292.

Mohan, V., Ramachandran, A., Snehalatha, C., Mohan, R., Bharani, G., & Viswanathan, M. (1985). High prevalence of maturity-onset diabetes of the young (MODY) among Indians. *Diabetes Care*, *8*(4), 371-374.

Mohan, V., Sharp, P. S., Aber, V. R., Mather, H. M., & Kohner, E. M. (1986). Family histories in Asian and European non-insulin-dependent diabetic patients. *Practical Diabetes International*, *3*(5), 254-256.

Mohan, V., Vijayaprabha, R., Rema, M., Premalatha, G., Poongothai, S., et al. (1997). Clinical profile of lean NIDDM in South India. *Diabetes Research and Clinical Practice*, *38*(2), 101-108.

Mohan, V. (2004). Why are Indians more prone to diabetes? *The Journal of the Association of Physicians of India*, *52*, 468-74.

Mohan, V., Shanthirani, C. S., & Deepa, R. (2003). Glucose intolerance (diabetes and IGT) in a selected South Indian population with special reference to family history, obesity and lifestyle factors--the Chennai Urban Population Study (CUPS 14). *The Journal of the Association of Physicians of India*, *51*, 771-7.

Mohan, V., Deepa, M., Deepa, R., Shanthirani, C. S., Farooq, S., Ganesan, A., & Datta, M. (2006). Secular trends in the prevalence of diabetes and impaired glucose tolerance in urban South India - the Chennai Urban Rural Epidemiology Study (CURES-17). *Diabetologia*, *49*(6), 1175-1178.

Mohan, V., Sandeep, S., Deepa, R., Shah, B., & Varghese, C. (2007). Epidemiology of type 2 diabetes: Indian scenario. *Indian Journal of Medical Research*, *125*(3), 217.

Mohan, V., Mathur, P., Deepa, R., Deepa, M., Shukla, D. K., et al. (2008). Urban rural differences in prevalence of self-reported diabetes in India—The WHO–ICMR Indian NCD risk factor surveillance. *Diabetes Research and Clinical Practice*, *80*(1), 159-168.

Mostafa, S. A., Khunti, K., Srinivasan, B. T., Webb, D., & Davies, M. J. (2011). Detecting type 2 diabetes and impaired glucose regulation using glycated hemoglobin in different populations. *Diabetes Management*, *1*(1), 77-97.

Mozaffarian, D., Kumanyika, S. K., Lemaitre, R. N., Olson, J. L., Burke, G. L., & Siscovick, D. S. (2003). Cereal, fruit, and vegetable fiber intake and the risk of cardiovascular disease in elderly individuals. *Journal of the American Medical Association*, *289*(13), 1659-1666.

National Institute of Nutrition. (2009). Nutrition requirements and recommended dietary allowances for Indians: A report of the Expert Group of the Indian Council of Medical Research. Available at: http://icmr.nic.in/final/RDA-2010.pdf. Accessed 5 Feb 2017.

Nayak, H. K., Vyas, S., Solanki, A., & Tiwari, H. (2011). Prevalence of type 2 diabetes in urban population of Ahmedabad, Gujarat. *Indian Journal of Medical Specialities*, *2*(2).

Patandin, S., Bots, M. L., Abel, R., & Valkenburg, H. A. (1994). Impaired glucose tolerance and diabetes mellitus in a rural population in south India. *Diabetes Research and Clinical Practice*, *24*(1), 47-53.

Pingali, P., & Khwaja, Y. (2004). Globalisation of Indian diets and the transformation of food supply systems. *Indian Journal of Agricultural Marketing*, *18*(1), 2004.

Planning Commission. (2012). Twelfth Five Year Plan. Available at: http://planningcommission.gov.in/plans/planrel/12thplan/pdf/12fyp_vol3.pdf. Accessed 20 Jan 2017.

Planning Commission. (2015). GDP at Factor Cost at 2004-05 Prices, Share to Total GDP and % Rate of Growth in GDP (31-05-2014). Available at: http://planningcommission.nic.in/data/datatable/0306/table%203.pdf. Accessed 20 Jan 2017.

Popkin, B. M. (1993). Nutritional patterns and transitions. *Population and Development Reviews*, 138-157.

Popkin, B. M., & Gordon-Larsen, P. (2004). The nutrition transition: worldwide obesity dynamics and their determinants. *International Journal of Obesity*, *28*, S2-S9.

Prabhakaran, D., Shah, P., Chaturvedi, V., Ramakrishnan, L., Manhapra, A., & Reddy, K. S. (2005). Cardiovascular risk factor prevalence among men in a large industry of northern India. *National Medical Journal of India*, *18*(2), 59.

Radhakrishna, R., & Subbarao, K. (Eds.). (1997). *India's public distribution system: a national and international perspective* (Vol. 380). World Bank Publications.

Radhika, G., Van Dam, R. M., Sudha, V., Ganesan, A., & Mohan, V. (2009). Refined grain consumption and the metabolic syndrome in urban Asian Indians (Chennai Urban Rural Epidemiology Study 57). *Metabolism, 58*(5), 675-681.

Raji, A., Seely, E. W., Arky, R. A., & Simonson, D. C. (2001). Body fat distribution and insulin resistance in healthy Asian Indians and Caucasians. *The Journal of Clinical Endocrinology & Metabolism*, *86*(11), 5366-5371.

Ramachandran, A., Snehalatha, C., Latha, E., Vijay, V., & Viswanathan, M. (1997a). Rising prevalence of NIDDM in an urban population in India. *Diabetologia*, *40*(2), 232-237.

Ramachandran, A., Snehalatha, C., Viswanathan, V., Viswanathan, M., & Haffner, S. M. (1997b). Risk of noninsulin dependent diabetes mellitus conferred by obesity and central adiposity in different ethnic groups: a comparative analysis between Asian Indians, Mexican Americans and Whites. *Diabetes Research and Clinical practice*, *36*(2), 121-125.

Ramachandran, A. (2007). Socio-economic burden of diabetes in India. *Journal of Association of Physicians of India*, *55*(L), 9.

Ramachandran, A., Mary, S., Yamuna, A., Murugesan, N., & Snehalatha, C. (2008). High prevalence of diabetes and cardiovascular risk factors associated with urbanization in India. *Diabetes Care*, *31*(5), 893-898.

Raut-Marathe, S., Sardeshpande, N., & Yakkundi, D. (2015). What Causes Medicine Shortages in Primary Health Centres? A Case Study of Availability and Supply System of Medicines in Select PHCs from Maharashtra. *Journal of Health Management*, *17*(1), 86-97.

Reddy, K. S., Shah, B., Varghese, C., & Ramadoss, A. (2005). Responding to the threat of chronic diseases in India. *The Lancet*, *366*(9498), 1744-1749.

Rema, N., & Vasanthamani, G. (2011). Prevalence of nutritional and lifestyle disorders among school going children in urban and rural areas of Coimbatore in Tamil Nadu, India. *Indian Journal of Science and Technology*, *4*(2), 131-140.

Rosenbloom, A. L., Joe, J. R., Young, R. S., & Winter, W. E. (1999). Emerging epidemic of type 2 diabetes in youth. *Diabetes Care, 22*(2), 345-354.

Sadikot, S. M., Nigam, A., Das, S., Bajaj, S., Zargar, et al. (2004). The burden of diabetes and impaired glucose tolerance in India using the WHO 1999 criteria: prevalence of diabetes in India study (PODIS). *Diabetes Research and Clinical Practice, 66*(3), 301-307.

Samuel, P., Antonisamy, B., Raghupathy, P., Richard, J., & Fall, C. H. (2012). Socio-economic status and cardiovascular risk factors in rural and urban areas of Vellore, Tamilnadu, South India. *International Journal of Epidemiology*, *41*(5), 1315-1327.

Sen S, Chakraborty R, De B, Devanna N (2015). Trends in diabetes epidemiology in Indian population in spite of regional disparities: a systematic review. *International Journal of Diabetes in Developing Countrie*s, 35(3):264-279.

Sharp, P. S., Mohan, V., Levy, J. C., Mather, H. M., & Kohner, E. M. (1987). Insulin resistance in patients of Asian Indian and European origin with non-insulin dependent diabetes. *Hormone and Metabolic Research*, *19*(02), 84-85.

Shetty, P. S. (2002). Nutrition transition in India. *Public Health Nutrition*, *5*(1A),175-182.

Siegel, K., Narayan, K. V., & Kinra, S. (2008). Finding a policy solution to India's diabetes epidemic. *Health Affairs*, *27*(4), 1077-1090.

Singh, R. B., Bajaj, S., Niaz, M. A., Rastogi, S. S., & Moshiri, M. (1998). Prevalence of type 2 diabetes mellitus and risk of hypertension and coronary artery disease in rural and urban population with low rates of obesity. *International Journal of Cardiology*, *66*(1), 65-72.

Slavin, J. (2003). Why whole grains are protective: biological mechanisms. *Proceedings of the Nutrition Society*, *62*(01), 129-134.

Srivastava, D. K., Shanmugam, K. R., & Bhujanga Rao, C. (2010). MDGs-Based Poverty Reduction Strategy for Tamil Nadu. Chennai, India: Madras School of Economics.

Thow, A. M., Kadiyala, S., Khandelwal, S., Menon, P., Downs, S., & Reddy, K. S. (2016). Toward Food Policy for the Dual Burden of Malnutrition An Exploratory Policy Space Analysis in India. *Food and Nutrition Bulletin*, 0379572116653863.

Tiwari, P., & Sankhala, A. (2007). Prevalence of obesity, weight perception and dietary behaviour of urban college going girls. *Journal of Human Ecology*, *21*(3), 181-183.

Toteja G. S., Sing, P., Dhillon, B. S., & Saxena, B. N. (2002). Vitamin A deficiency disorders in 16 districts of India. *Indian Journal of Pediatrics*, *69*. 603-605.

UK Prospective Diabetes Study Group. (1994). UK Prospective Diabetes Study XII: differences between Asian, Afro-Caribbean and white Caucasian type 2 diabetic patients at diagnosis of diabetes. *Diabetic Medicine*, *11*(7), 670-7.

Vaid, D. (2014). Caste in contemporary India: Flexibility and persistence. *Annual Review of Sociology*, *40*, 391-410.

Vaismoradi, M., Turunen, H., & Bondas, T. (2013). Content analysis and thematic analysis: Implications for conducting a qualitative descriptive study. *Nursing & Health Sciences*, *15*(3), 398-405.

Vepa, S. (2004). Impact of Globalization on the Food Consumption of Urban India. In Food and Agricultural Organization (ed.) *Globalization of Food Systems in Developing Countries: Impact on Food Security and Nutrition*. Rome: Food and Agricultural Organization, pp. 215–30

Vermunt, S. H. F., Pasman, W. J., Schaafsma, G., & Kardinaal, A. F. M. (2003). Effects of sugar intake on body weight: a review. *Obesity Reviews*, *4*(2), 91-99.

Vijayakumar, G., Arun, R., & Kutty, V. R. (2009). High prevalence of type 2 diabetes mellitus and other metabolic disorders in rural Central Kerala. *Journal of the Association of Physicians in India*, *57*(2), 563-67.

Viswanathan, M., Mohan, V., Snehalatha, C., & Ramachandran, A. (1985). High prevalence of type 2 (non-insulin-dependent) diabetes among the offspring of conjugal type 2 diabetic parents in India. *Diabetologia*, *28*(12), 907-910.

Wander, G. S., Khurana, S. B., Gulati, R., Sachar, R. K., & Gupta, R. K. (1994). Epidemiology of Coronary Heart Disease in a Rural Punjab Population-Prevalence and Correlation. *Indian Heart Journal*, *46*(6), 319-323.

World Health Organization. (2004). Appropriate body-mass index for Asian populations and its implications for policy and intervention strategies. *Lancet (London, England)*, *363*(9403), 157.

World Health Organization. (2006). Definition and diagnosis of diabetes mellitus and intermediate hyperglycaemia: report of a WH. Available at: http://apps.who.int/iris/bitstream/10665/43588/1/9241594934_eng.pdf. Accessed 12 Jan 2017.

World Health Organization. (2013). Global Action Plan for the Prevention and Control of Noncommunicable Diseases. Available at: http://apps.who.int/iris/bitstream/10665/94384/1/9789241506236_eng.pdf?ua=1. Accessed 20 Jan 2017.

World Health Organization. (2015). India: First to adapt global monitoring framework on noncommunicable diseases. Available at: http://www.who.int/features/2015/ncd-india/en/. Accessed 20 Jan 2017.

Yadav, K., & Krishnan, A. (2008). Changing patterns of diet, physical activity and obesity among urban, rural and slum populations in north India. *Obesity Reviews*, *9*(5), 400-408.

Yajnik, C. S., Fall, C. H. D., Vaidya, U., Pandit, A. N., Bavdekar, A., et al. (1995). Fetal Growth and Glucose and Insulin Metabolism in Four-year-old Indian Children. *Diabetic Medicine*, *12*(4), 330-336.

Yajnik, C. S. (2001). The insulin resistance epidemic in India: fetal origins, later lifestyle, or both? *Nutrition Reviews*, *59*(1), 1-9.

Yajnik, C. S., Lubree, H. G., Rege, S. S., Naik, S. S., Deshpande, J. A., et al. (2002). Adiposity and hyperinsulinemia in Indians are present at birth. *The Journal of Clinical Endocrinology & Metabolism*, *87*(12), 5575-5580.

Yajnik, C. S., Fall, C. H. D., Coyaji, K. J., Hirve, S. S., Rao, S., et al. (2003). Neonatal anthropometry: the thin–fat Indian baby. The Pune maternal nutrition study. *International Journal of Obesity*, *27*(2), 173-180.

Zaman, F. A., Pal, R., Zaman, G. S., Swati, I. A., & Kayyum, A. (2011). Glucose indices, frank and undetected diabetes in relation to hypertension and anthropometry in a South Indian rural population. *Indian Journal of Public Health*, *55*(1), 34.

Zargar, A. H., Khan, A. K., Masoodi, S. R., Laway, B. A., Wani, A. I., et al. (2000). Prevalence of type 2 diabetes mellitus and impaired glucose tolerance in the Kashmir Valley of the Indian subcontinent. *Diabetes Research and Clinical Practice*, *47*(2), 135-146.

Zimmet, P. (1982). Type 2 (non-insulin-dependent) diabetes—an epidemiological overview. *Diabetologia*, *22*(6), 399-411.

Zimmet, P. (2000). Globalization, coca-colonization and the chronic disease epidemic: can the Doomsday scenario be averted? *Journal of Onternal Medicine*, *247*(3), 301-310.

FIGURES

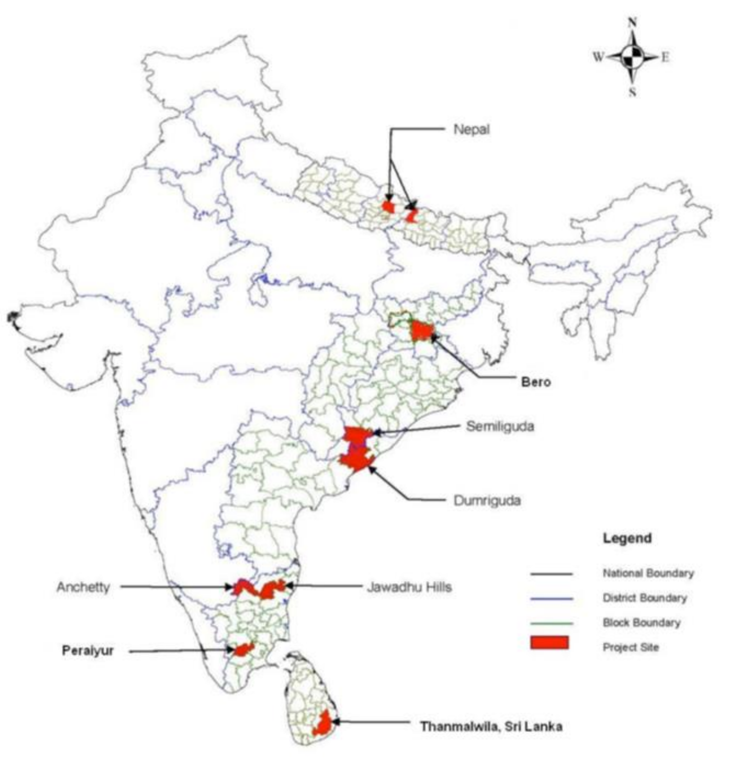

Figure 2.1: Research included in "Revalorizing small millets in rainfed regions of south India" (RESMISA) project

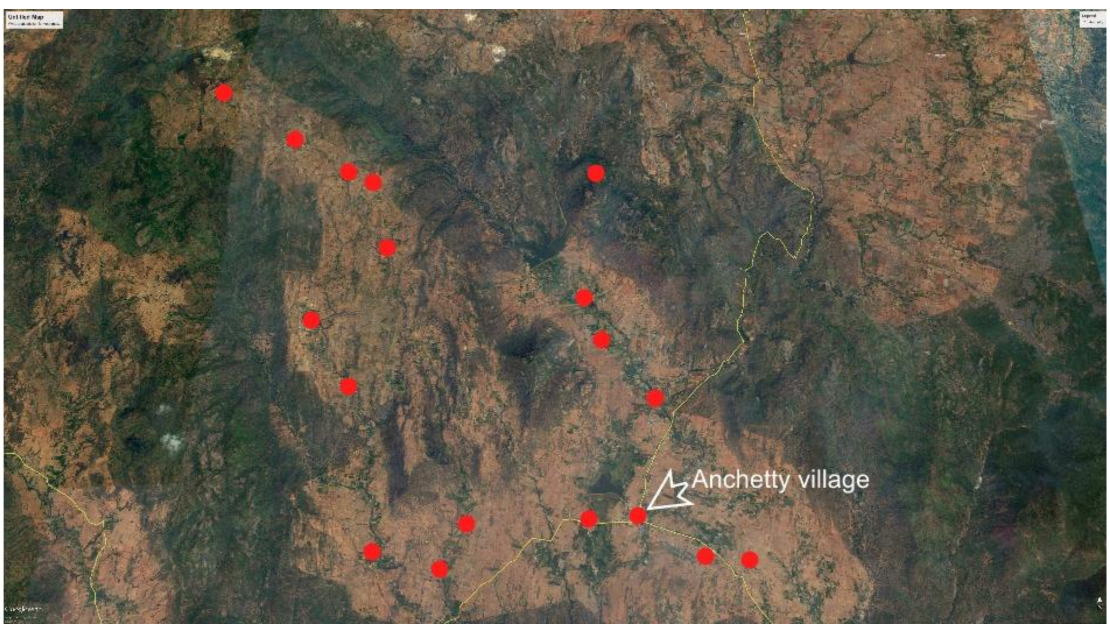

Figure 2.2: Anchetty region and villages included in cross-sectional study (n=753)

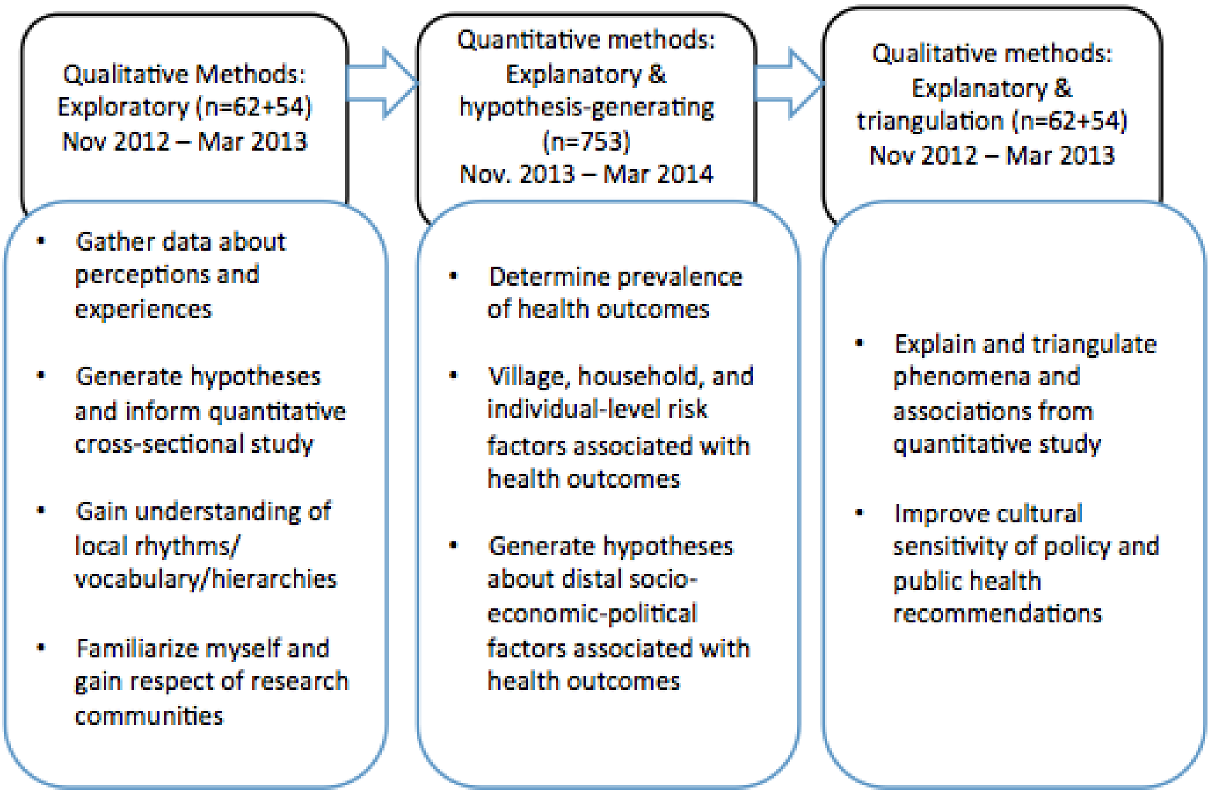

Figure 2.3 Schematic of research framework employed for data collection and analysis activities

CHAPTER THREE:

FACTORS ASSOCIATED WITH BMI, UNDERWEIGHT, OVERWEIGHT, AND OBESITY AMONG ADULTS IN A REGION OF RURAL SOUTH INDIA: A CROSS-SECTIONAL STUDY[1]

ABSTRACT

Background: Overweight, obesity, and related chronic diseases are becoming serious public health concerns in rural areas of India. Compounded with the existing issue of underweight, such concerns expose the double burden of malnutrition and may put stress on rural healthcare. The purpose of this article was to present the prevalence and factors associated with underweight, overweight, and obesity in an area of rural south India.

Methods: During 2013 and 2014, a random sample of adults (20-80 years) were selected for participation in a cross-sectional study that collected information on diet (using a food frequency questionnaire), physical activity (using the Global Physical Activity Questionnaire), socioeconomic position (using a wealth index), rurality (using the rurality index), education, and a variety of descriptive factors. BMI was measured using standard techniques. Using a multivariable linear and logistic regression analyses, we examined associations between BMI, overweight, obesity, and underweight, and all potential risk factors included in the survey.

Results: Age and sex-adjusted prevalence of overweight, obesity class I, and obesity class II were 15.8%, 17.7%, and 3.5% respectively. Prevalence of underweight was 22.7%. The following variables were associated with higher BMI and/or increased odds of overweight,

---

[1]*A version of this article is published as:* Little, M., Humphries, S., Patel, K., & Dewey, C. (2016). Factors associated with BMI, underweight, overweight, and obesity among adults in a population of rural south India: a cross-sectional study. *BMC Obesity*, *3*(1), 12.

obesity class I, and/or obesity class II: Low physical activity, high wealth index, no livestock, low animal fat consumption, high n-6 polyunsaturated fat consumption, television ownership, time spent watching television, low rurality index, and high caste. The following variables were associated with increased odds of underweight: low wealth index, high rurality index, and low intake of n-6 PUFAs.

Conclusion: Underweight, overweight, and obesity are prevalent in rural regions of southern India, indicating a village-level double burden of malnutrition. To address the both underweight and obesity, policymakers must simultaneously focus on encouraging positive behaviour through education and addressing society-level risk factors that inhibit individuals from achieving optimal health.

3.1 Background

Obesity and its associated health effects are quickly becoming serious health concerns in low- and middle-income countries [1]. In 2010, the World Obesity Federation estimated that over one billion adults were overweight and 475 million adults were obese globally [2], the majority of which resided in developing countries in Latin America, Africa, and Asia. In India, successive studies suggest obesity is increasing rapidly, with recent prevalence estimates upwards of 15% [3]. The sedentary and dietary effects of urbanization and modernization are often blamed for propagating overweight and obesity [4], however little research has examined the risk factors contributing to rising prevalence in rural areas where 70% of the Indian population live and modernization has occurred less rapidly [5]. In-depth examinations of overweight and obesity in rural regions are therefore essential, especially considering these regions are often compromised by low literacy and poor access to healthcare services [6].

Overweight and obesity are associated with increased risk of non-communicable diseases such as metabolic syndrome, high cholesterol, type 2 diabetes mellitus, high blood pressure, and cardiovascular disease; conditions that are already serious public health concerns in rural and urban India alike [5,7]. Studies of non-communicable disease biomarkers have long conferred the possibility of an ‘Asian Indian phenotype’ that produces higher-risk central adiposity at a lower body-mass index (BMI) than comparable populations in Europe and North America. For example, Razak et al. [8] found that average fasting glucose levels, LDL cholesterol concentrations, and blood pressure found in Europeans at a BMI of 30 kg/m^2 could be found in Asian Indians at a much lower BMI. Such studies indicate that Asian Indians are more susceptible to the negative health consequences of overweight and obesity. Even more troubling is the co- occurrence of under-nutrition and over-nutrition in rural villages and households, termed the ‘double burden’ of malnutrition, which serves to exacerbate poverty and limit economic growth in these areas [9]. While a number of studies have examined associations between dietary and lifestyle factors and prevalence of underweight, overweight, and obesity in the United States [10,11] and Europe [12,13], little research has examined similar associations in India, and even fewer in rural India [5].

The present study was conducted from November 2013 to March 2014 and examined a random sample of 753 people living in a rural region of northern Tamil Nadu. The objectives of the study were: (1) to determine the prevalence of underweight, overweight, and obesity among the study population; and (2) to determine the risk factors that affect BMI, underweight, overweight, obesity in rural regions of India using forwards stepwise linear and logistic regression models. The study was carried out in collaboration with the Development for Humane Action Network (DHAN) Foundation as part of an interdisciplinary international development project entitled “Revalorizing small millets: Enhancing the food and nutritional security of women and children in rainfed regions of South Asia using underutilized species", funded by the International Development Research Centre and the Department of Foreign Affairs, Trade, and Defense (formerly the Canadian International Development Agency and now Global Affairs Canada).

3.2 Methods

3.2.1 Ethics, consent, and permissions

We obtained clearance for the study from the University of Guelph Research Ethics Board (certificate reference number 12MY019). Permission for the study was granted by the High Commission of India in Ottawa, Canada. Upon arrival to the research site, and prior to the recruitment process, we approached local authorities (*panchayat* councils, local police officials, and hospital medical staff) and sought and obtained permission to carry out the study. Informed consent to participate in the study was obtained from all participants prior to their enrollment.

3.2.2 Sampling frame and recruitment

The sampling frame consisted of the entire adult population (>19 years old) of two rural *panchayat* wards (Anchetty panchayat and Madakkal panchayat), in the Krishnagiri District of Tamil Nadu. The region is comprised of several small villages surrounding the central market village of Anchetty. Our target was to sample 800 participants following a sample size calculation for a sub-study published elsewhere [14]. A randomized two-stage recruitment method was employed, in which we first approached a random sample of 8% of households in the sampling frame, then employed the WHO's Kish method to select a single household member for the study [15,16]. If the selected individual refused, we removed them from the list of occupants and employed the Kish method again until the selected individual agreed to participate. If all adult members of the household were not present or refused, we moved to an immediately neighbouring household to recruit the required sample. All absences and refusals were considered non-responses in calculating response rate. We recorded the reason for non-response whenever possible. After securing oral consent to participate in the study, we organized a follow-up for completion of surveys and collection of health outcome data. A gender-matched research assistant collected anthropometric measurements and one of two nutritionists conducted all interviews.

3.2.3 Anthropometric measurements and descriptive questionnaire

Standing height was measured at end of expiration against a flat wall using a ruler pressed against the crown of the head and a measuring tape. Weight was measured in light clothes with bare feet using a household digital scale (NOVA™ BGS1207 model). Blood pressure measurements were recorded as the average of two readings using an Omron™ BP786-10 handheld electronic blood pressure monitor in the sitting position using the right upper arm and one of three sized cuffs after a period of 5 minutes sitting. Participants completed a structured questionnaire about age, sex, occupation, education, medical history, tobacco use, socioeconomic status, physical activity, and dietary intake.

3.2.4 Socio-economic status wealth index

We created a wealth index using a modified subset of 13 of 29 questions taken from the Standard of Living Index used by the 2nd round of the National Health and Family Survey (Table A1.1, Appendix 1) [17]. We selected those questions we believed to be most relevant for our study population. They comprised both household and village characteristics, including: electrification (electricity, kerosene, gas or oil, other source of lighting), source of drinking water (pipe, hand pump, well in residence, public tap, hand pump, public well, or other water source), type of toilet facility (own flush toilet, public or shared flush toilet or own pit toilet, shared or public pit toilet, no facility), type of house (pucca, semi-pucca, or kutcha), cooking fuel (electricity, natural gas, kerosene, or wood). In addition, we collected information on ownership of house, land, livestock (cattle, chickens, goats, sheep, and buffalo), radio, vehicle (bicycle, moped, motorcycle, or car), and television. Each attribute was weighted to give a maximum score of 41. Weights of items were developed by the International Institute of Population Sciences in India based on a priori knowledge about the relative significance of the items in determining socio-economic status (SES) [18]. Due to the rural subsistence nature of the local economy, this asset-based score is considered a more appropriate indicator of SES than education, income, or occupation [17]. For the remainder of the article, we will refer to this score as the 'wealth index'.

3.2.5 Rurality index

All previous epidemiology studies in India known to the authors define households as either rural or urban based on a dichotomous typology, which fails to adequately capture the variability inherent in the urban/rural continuum [19]. We created a rurality index to quantify the degree of rurality of each household. This index was based on that developed for the USA by Weinert and Boik (1995) and adapted for use in India [20]. The index was based on two factors: (1) distance to primary health centre, and (2) population of village in which household resides. We collected and standardized these values, then combined them, assigning a half weighted positive value to 'distance to healthcare facility' and a full weighted negative value to 'household population village'.

3.2.6 Physical activity assessment

We conducted the Global Physical Activity Questionnaire (GPAQ) with each participant, designed by the World Health Organization (WHO) as part of the WHO STEPwise approach to chronic disease risk factor surveillance [21]. GPAQ comprises 19 questions grouped to assess individuals' physical activity behaviour in three main domains over the course of one year: work, travel, and recreation. The GPAQ was paired with locally relevant photographs depicting 'moderate' and 'vigorous'-intensity work and recreation activities. In addition, we collected time spent sitting and time spent watching television per day. Physical activity scores were calculated using WHO's GPAQ Analysis Guide [21], which provided a total measure of Metabolic Equivalent (MET) minutes per week based on amount of time spent performing moderate (assigned 4 MET equivalents per minute) and vigorous physical activity (assigned 8 MET equivalents per minute) for work, transport, and recreation purposes. We scaled values to hours per day of moderate physical activity for easier interpretation.

3.2.7 Dietary and nutrition assessment

Diet was assessed using a south Indian food frequency questionnaire (FFQ), validated for Tamil Nadu by the Madras Diabetes Research Foundation (MDRF) [22]. MDRF provided permission to use the research tool and organized a three-day training program for our three nutritionists on how to properly administer the FFQ, record responses, and enter data using their data entry software model. The FFQ uses a food atlas with photographs of dishes and serving sizes to collect information about the frequency of consumption of 223 dishes and foods. This tool is paired with EpiNu® [23], a software program that calculates overall intake of food categories and macro- and micronutrients based on frequency of consumption of dishes and laboratory-based nutritional analyses for each dish [24]. After completion of the study, FFQ data was analyzed by MDRF using EpiNu®, providing us with detailed data about dietary and nutrient intake for each participant. Energy intake was analyzed as kilocalories (kcal) consumed per day. All other dietary intake variables were scaled to grams per 1000 kcal consumed.

3.2.8 Definitions

Literacy was defined as self-professed fluency in reading and writing. Tobacco consumers were defined as individuals who currently smoked at least one cigarette and/or chewed *paan* at least once per day. High blood pressure was defined as mean systolic blood pressure ≥ 140 mm Hg and/or mean diastolic blood pressure ≥ 90 mm Hg and/or treatment with blood pressure medication [25]. For each participant we calculated the body mass index (BMI) as the weight in kilograms divided by the squared height in meters (kg/m^2).

As per the definitions of the International Obesity Task Force (IOTF), underweight was defined as BMI<18.5 kg/m^2, overweight was defined as BMI ≥ 23.0 kg/m^2 but <25 kg/m^2, obesity class I was defined as BMI ≥ 25 kg/m^2 and < 30 kg/m^2, and obesity class II was defined as BMI ≥ 30 kg/m^2 [26]. Low caste was analyzed as a binary variable with Scheduled Castes (SC) and Scheduled Tribes (ST) being low caste and all others as an amalgamated referent. High caste was analyzed as a binary variable, with Brahmins being high caste and all other castes as an amalgamated referent.

3.2.9 Statistical analysis

We identified outliers, cleaned the data set, and completed summary statistics in Microsoft Excel 10.0 [27]. No values were considered outliers after correcting data entry errors. As such, all observations were included in the analysis.

Underweight, overweight, and obesity prevalence data were standardized using state-level age and sex data from the 2011 national census [28]. In separate models, univariate associations between sex and BMI category were analyzed. Since there were no significant associations between sex and outcome variables, we present the results for men and women combined. Means of descriptive characteristics, socioeconomic and education characteristics, physical activity habits, and dietary intake were calculated across categories of BMI, including underweight, normal, overweight, obesity class I, and, obesity class II. Values were expressed as mean +/- SD or percentages. One-way analyses of variance (for continuous variables) and Pearson's X^2 test were used to examine differences across outcome groups. Following this, three multivariable regression models were built in STATA 13.0 [29].

3.2.9.1 Model one

We employed a forward stepwise linear regression model-building process to determine associations between BMI as a continuous variable and putative risk factors. All factors were first analyzed in univariate regressions (see Appendix 2 for full list of factors). Variables with significant associations (p-value<0.2) in univariate analyses were considered for an initial multivariable linear regression model. We then employed a forward stepwise model building process and eliminated non-significant variables (using a p-value cut-off of 0.05) from the multivariable model, assuming a lack of confounding if coefficients of all remaining variables did not change by more than 20% after addition or removal of the potential confounder [30]. Quadratic terms and interaction terms were assessed if there were biological or practical reasons to believe they may be significant. BMI was log-transformed to improve normality of residuals and homoscedasticity. We ensured the transformed model obeyed the assumptions of linear regression models, including independence of variables, normality of residuals (using a Shapiro-Wilks test and quartile quartile plots), and homoscedasticity (using a Cook-Weisberg test and a residual-fitted value plot).

3.2.9.2 Model two

In a second step, we fit a multinomial logistic regression with overweight, class I obesity, and class II obesity as separate outcome groups. Underweight and normal weight classes were combined into a referent category to increase the statistical power of the analysis [31]. We examined the same variables as those assessed in the linear regression analysis (Appendix 2). Variables were first assessed for significance in multinomial univariate logistic analyses. All variables with associations (p-value <0.2) with any of the outcome groups were included in the initial multivariable analysis. We then employed a forward stepwise process and eliminated non-significant variables (p-value <0.05) using the same methods as those used in model one to determine adjusted odds ratios (ORs) and 95% confidence intervals (CIs).

3.2.9.3 Model three

In a final step, we fit a multivariable logistic regression with underweight as an outcome group. All other weight categories were combined as the referent group [32]. We examined the same variables as those assessed in the models one and two (see Appendix 2). We then followed the same methods as used in model two in order to determine adjusted ORs and corresponding CIs for each significant variable (p-value<0.05) in the final model.

3.3 Results

Of the 812 individuals recruited for the study, 753 (92.7%) participated (341 men and 412 women), of whom 752 (92.6%) completed an FFQ and 745 (91.7%) consented to anthropometric measurements. Response rate was 87.4% among men and 99.2% among women. Disparity in the response rate was primarily due to migration among local men and thus unavailability at the time of sampling. The mean age was 47±14.7 and the literacy rate was 35.1%. Crude prevalence of underweight, overweight, obesity class I, and obesity class II were 22.7%, 15.8%, 17.7%, and 3.5%, respectively. Age- and sex- adjusted prevalence of underweight, overweight, obesity class I, and obesity class II were 22.7%, 14.9%, 16.1%, and

3.3% respectively.

Baseline characteristics for the study population by BMI category are outlined in Table 3.1. A significant difference was seen across categories in several characteristics, including socioeconomic status, education, physical activity, sitting time. Intakes of carbohydrates, total fat, dietary fibre, pulses, and fruits and vegetables were significantly different by BMI category.

3.3.1 Model one: Linear regression of BMI

The multivariable linear regression model (Table 3.2) had an R-squared value of 0.20, indicating 20% of the variance in BMI among participants was explained by the variables included in the model. After adjustment for all potential confounders, there existed positive associations between BMI and wealth index, TV time, n-3 polyunsaturated fatty acid (PUFA) consumption, and high caste. There were inverse associations between BMI and physical activity, livestock ownership, rurality, animal fats consumption, and tobacco consumption. We repeated the analysis using log-transformed BMI to improve normality of residuals and homoscedasticity. As the results were very similar, we present here the fitted coefficients without transformation for ease of interpretation [33].

3.3.2 Model two: Multinomial logistic regression of overweight and obesity

Table 3.3 shows factors associated with overweight, obesity class I, and obesity class II based on a multinomial logistic regression. Normal and underweight individuals were amalgamated into the referent group. The model was not adjusted for age and sex because neither was significantly associated with any outcome group in the final model.

3.3.3 Model three: Multinomial logistic regression of underweight

Table 3.4 shows the factors associated with underweight determined by a logistic regression. Only three variables were significantly associated with odds of underweight in the final model.

3.4 Discussion

Age and sex-adjusted prevalence of underweight, overweight, obesity class I, and obesity class II were 22.7%, 14.9%, 16.1%, and 3.3%, respectively. Prevalence of underweight, overweight, and obesity class I was not significantly different between women and men ($p>0.05$). Obesity class II was more common among women ($p<0.05$), a finding that is consistent with several other studies in India [34,35]. Age and sex-adjusted prevalence of underweight was lower than the latest (2005) national rural estimate of 35%, indicating less under-nutrition in the study site than elsewhere in India [3]. Age and sex-standardized prevalence of obesity was higher than the latest national rural estimate of 6% [34], which is likely partially due to different BMI cut-off values and age differences in the sample population. Prevalence of overweight and obesity were comparable to more recent studies in rural south India that used similar cut-off values and age categories [34,36]. For example, Misra et al. (2011) found prevalence of overweight and obese were 14% and 18% in rural Tamil Nadu [35].

The simultaneous high prevalence of underweight and overweight/obesity indicates continued existence of the ‘double burden’ of malnutrition as described by Doak et al. (2005) [8]. While we were unable, due to sampling methods, to determine if underweight and overweight persons cohabit the same households, our findings do indicate the coexistence of underweight and overweight at the village level. Similar results have been found in agricultural regions of Brazil [37], South Africa [38], Russia [39], and China [40]. With age and sex-standardized prevalence of underweight and overweight/obesity accounting for over half the study population, and the potential for future increases in prevalence of overweight/obese as well as complications due to associated non-communicable diseases, the double burden of malnutrition should be considered a major concern that threatens to strain the limited health care services in the region.

3.4.1 Correlates of underweight, overweight, and obesity

While most studies examining risk factors contributing to underweight, overweight, or obesity categorize or dichotomize BMI and analyze associations using logistic regressions [e.g. 6,12,13,41], there is a large body of literature suggesting that categorizing continuous variables isn't statistically effective as it results in a loss of information and power due to a reduction of variability in each category [42,43,44]. For this reason, we conducted linear regressions in addition to logistic regressions. We found strong independent associations between several risk factors and BMI, underweight, overweight, and obesity.

3.4.1.1 Physical activity

In the unadjusted univariate model, each hour per day of moderate physical activity was associated with a 0.095 kg/m^2 decrease in BMI. After adjusting for other variables, each hour of moderate physical activity per day was associated with a 0.085 kg/m2 decrease in BMI. This is equivalent to -231 g for a typical Indian man (165 cm tall) and -196 g for a typical Indian woman (152 cm tall) (based on height data from Mamidi et al. 2011 [45]). Although the magnitude of this difference may seem small, when the coefficient was applied to the values for low (10th percentile of PA scores) versus high (90th percentile), the model predicted a difference of -2.34 kg for a typical man and -1.99 kg for a typical woman. In addition, higher physical activity was associated with lesser odds of obesity class I and obesity class II. These findings support suggestions by Shetty and colleagues (2002) that reduced physical activity is one of the main causes of overweight and obesity in India [46]. Due to the cross-sectional nature of the study, we are unable to determine if reduced physical activity is a cause or a consequence of weight gain [27,47]. Physical activity was not associated with underweight despite suggestions by Hausenblas and Downs that excessive exercise (e.g. forced labour) could lead to underweight and wasting [48,49]. However, it is unlikely that such individuals were captured in the study.

Several researchers suggest that modernization has contributed to declining physical activity in a number of ways. An influx of vehicles has reduced the need for active transportation [5]. Mechanization of farming processes has resulted in less need for strenuous labour. For example, Ramachandran et al. (2004) found a 57.2% decrease in the number of individuals engaged in manual labour in a rural population of eastern Tamil Nadu between 1989 and 2003 [50]. Exercise for leisure is not common in rural India, so reduced physical activity for work or travel is rarely offset by recreational activities [51]. Taking into account the growing prevalence of overweight and obesity in India, our findings are consistent with the view that physical activity may reduce or prevent increases in body weight. Our results suggest that even a modest level of activity may confer health benefits.

3.4.1.2 Rurality index

The Census Bureau of India classifies households as either urban or rural and policymakers enforce these definitions in health, food, and economic policies [52]. Researchers in India have adopted this definition when examining the effects of urbanization on chronic disease outcomes, often making comparisons between rural and urban populations [35,53,54,55,56]. However, a dichotomous definition of rurality is ineffective when examining rural or urban populations separately. In addition, it fails to account for the gradient of rurality, homogenizes a heterogeneous population, and oversimplifies the effects of rurality as a descriptive factor [57]. Indeed, as stated by Rousseau (2005), 'rural' should not imply a single community but a wide range of communities with various features [58]. A standardized definition of rurality has thus proved elusive, and the effects of rurality are characterized by a complex and context-specific interplay of culture, affluence, geography, agriculture, and access to markets. Several studies have confirmed that urban status is associated with higher BMI and greater odds of overweight and obesity and rural status is associated with greater odds of underweight [35,53,54,55]. Many of these studies described associations between urban or rural status and other more proximate risk factors, such as income, physical activity, and diet (e.g. Pandey et al. 2013 [54]). While in our study, the entire study region is classified as rural, we were interested in the more nuanced conceptualization of a rural-urban continuum [59,60]. In light of the many public health problems posed by urbanization, we believe it prudent to quantify and examine this concept in an epidemiologic capacity.

Researchers in the United States [20], Canada [61,62], Australia [63], and Britain [64] have developed localized rurality indices intended to quantify the rural-urban continuum for researchers, policymakers, and healthcare providers. However, no rurality index has been developed for India. We elected to adapt a rurality index developed by Weinert and Boik (1995) [20] due to its simplicity and relevance to the Indian context. Our results showed greater rurality was associated with lower BMI and decreased odds of overweight, class I obesity, and class II obesity. In addition, increased rurality was associated with greater odds of underweight. We therefore posit that degree of rurality is accompanied by a gradient of lifestyle and dietary differences not captured by other measures. In addition, individuals living in larger villages and closer to the market may experience processes associated with urbanization while still maintaining their rural status as per the Indian definition. Some studies have suggested urban residents face greater stress loads and higher prevalence of depression, which in turn affects physical health and possibly BMI [65,66]. As we did not collect or analyze any measure of stress, perhaps the effects of such 'hidden' risk factors are captured by the rurality index. Further research on rurality and health outcomes is crucial to encourage policymakers to reevaluate the simplistic rural/urban dichotomy upon which most health, food, and economic policy is founded.

3.4.1.3 Socio-economic status (SES)

The asset-based wealth index, analyzed as a proxy for SES, was positively associated with BMI and greater odds of obesity class I and obesity class II. Low wealth index was also associated with increased odds of underweight. Considering the large variance of the wealth index (our values ranged from one to 26), the magnitude of differences between predicted values of BMI is large. When the coefficient was applied to the values for the 10^{th} and 90^{th} percentile of wealth index values, the model predicted a difference of 4.57 kg for a typical man and 3.88 kg for a typical woman.

It is likely that SES acts is a distal factor and the exact mechanisms through which it may affect odds of underweight, overweight, and obesity are varied [67]. Families with higher socioeconomic status likely differ in their lifestyle – including dietary and physical activity patterns – thus affecting risk. While we examined these factors, the wealth index may have captured excess variability not accounted for by our assessments. Associations between socioeconomic markers (education, income, and possession-based wealth indices) and obesity have been found in other recent studies of rural individuals [6,68]. Those of lower SES were more likely to be underweight, a result that is consistent with other studies in rural Tamil Nadu

[69] and elsewhere in India [6]. This finding corresponds with the large body of research suggesting socioeconomic status is associated with limited food intake and excessive manual labour, thus making it difficult for individuals to achieve net positive energy intake required to maintain or gain weight [6,19,34]. Such associations support the theory that social determinants play a role in both over- and under-nutrition [70].

3.4.1.4 Livestock ownership

A unique finding of the present study was the inverse association between livestock ownership and BMI. Although livestock ownership was included in the wealth index, it was also independently associated with lower BMI when controlling for extemporaneous variables. Due to the lack of formal research on this topic, our knowledge of this association is limited to conjecture. In rural Tamil Nadu, most farmers graze their animals on forested public lands [71,72], which often leads to individuals walking long distances every day to access fodder for their livestock. The result may be higher energy expenditure not fully captured by the PA score. Livestock ownership may also increase accessibility to milk products and lean meats such as chicken and mutton, thus resulting in increased consumption of animal proteins. Regardless, this association merits further investigation on a larger scale.

3.4.1.5 Television ownership and TV time

Prevalence of television ownership was very high at 88.1%. Although comparative data from other studies in India are rare, we found higher ownership rates than those reported by the 2006 National Readership Study, which found televisions in 76.2% of households in Tamil Nadu [73]. Our findings are likely attributable to a populist scheme launched by the ruling Tamil Nadu state political party in 2006 to distribute colour televisions to the poor [74]. Over the following 4 years, the government purportedly delivered over 13.7 million televisions to

Tamil Nadu residents [75].

Television ownership was associated with higher odds of overweight and class I obesity. This association is likely two-fold. First, television ownership may be indicative of overall wealth and SES. Although it was included in the wealth index, due to high prevalence of television ownership (Table 3.1) and its relatively low weight in the aggregate score, it may have had a small impact on wealth index and thus is also independently indicative of SES. This may indicate that some poor families were overlooked by the free TV scheme, or sold the televisions they received. Second, television ownership may encourage sedentary leisure time. Indeed, we found that time spent watching television (TV time) was associated with higher BMI and increased odds of class I obesity. TV time has been linked with overweight and obesity among children in other areas of India, however this is the first study to find such an association among adults [76]. Sitting time was not significantly associated with any outcome, contrary to findings in other countries [77]. It is possible that television ownership and TV time are more accurate indicators of sedentary leisure time than reported sitting time due to response bias (likely recall bias and social desirability bias).

3.4.1.6 High caste

High caste was associated with higher BMI and increased odds of obesity class I. These results correspond with those of Gaiha et al. (2010) [69], who found that low caste (including SC, ST, and other backward castes (OBC)) was associated with lower risk of obesity. Similarly, Adinatesh et al. (2013) [78] found a higher prevalence of overweight and obesity among higher-caste individuals when compared to SC, ST, or OBC individuals. This association is likely complex, but we conjecture that it is likely due to two main categories of factors: lifestyle factors and genetic differences. As seen by Adinatesh and colleagues, high caste populations tend to have lower under-nutrition, higher income and standards of living, greater access of sedentary pastimes (e.g. television, video games), and increased usage of vehicles for transportation [78]. In addition, geneticists have recently discovered genetic differences between castes, with higher castes having a higher proportion of West Eurasian genetic admixture [79]. Unfortunately, no research has yet examined caste genetics as they pertain to health and disease outcomes. Considering the roles of genetic factors in development of overweight and obesity [80], genetic differences between castes may play an important role in the association between caste and BMI. More research is needed to explore the ongoing role of caste and caste genetics in determining risk of overweight and obesity in rural areas.

3.4.1.7 Tobacco consumption

In India, tobacco is consumed in various forms. Cigarettes are growing in popularity, especially among urban and high-income populations [81]. Bidis (thin hand- rolled tobacco leafs) are cheaper and more commonly smoked among lower-income and rural populations. In addition, use of smokeless tobacco is pervasive among both men and women. Smokeless tobacco is often consumed in combination of betel-leaf, areca nut as a product called *paan* [82]. We found that any-type tobacco consumption was associated with lower BMI and lower odds of obesity class II. Tobacco use was also associated with increased odds of underweight. These findings are consistent with previous studies in the US [83,84,85] and urban India [86]. While the reasons behind this association are varied and complex, it is likely that tobacco may act directly (by affecting appetite and other aspects of physiology) or indirectly (by decreasing the purchasing power for food and therefore quality of diet) [82]. Considering the implications of tobacco consumption on both risk of underweight and risk of cancers and cardiovascular diseases, public health programs must emphasize preventing tobacco use and supporting cessation efforts among addicted individuals.

3.4.1.8 Dietary factors

India is experiencing a nutrition transition characterized by decreased consumption of coarse cereals and dietary diversification [44]. In some ways, this has benefited rural nutrition; data from the past 40 years suggest that fruit and vegetable consumption has doubled and overall protein intake has improved [4]. However, there have been significant drawbacks. Traditional small millets have been replaced by refined wheat and polished white rice due to imbalanced subsidization and shifting taste preferences [87]. Consumption of fats and sugars is also increasing due to the rising popularity of snack foods. We examined intake of foods, food groups, macro-nutrients, and micro-nutrients for potential associations with BMI, overweight, and obesity. We found significant associations with dietary intake of n-6 polyunsaturated fatty acids and animal fats.

3.4.1.8.1 Oil consumption

The role of dietary fats in adult human obesity is a controversial issue [88]. A review by Willett (2001) [89] concludes that diets high in fat do not account for high prevalence of excess body fat in Western countries, and that the emphasis on total fat reduction has been a "serious distraction in efforts to control obesity and improve health in general" (pp. 59). His argument is based on both epidemiological evidence showing a poor association between total fat intake and obesity, and an assessment of published clinical trials that examine changes in fat composition in the diet. By contrast, a separate review conducted by Bray and Popkin (1998) [90] concludes that fat intake does promote obesity through passive overconsumption. Animal studies show a strong association between high-fat diets and obesity, and some studies on humans found that increasing fat intake was associated with an increase in BMI and higher odds of obesity [91,92]. Bray and Popkin conclude that a reduction in dietary fat should be seen as a means to reduce to reduce total energy intake and reduce the energy density of the diet. The debate is inconclusive and as yet there is no consensus in the literature about the association between fat intake and BMI, overweight, and obesity.

Evidence from the present study suggests that such reviews may disregard the qualitative composition of fat intake and the role of different types of fats. Intake of n-6 (also called omega-6) polyunsaturated fatty acids (PUFAs) was positively associated with BMI and negatively associated with odds of underweight. Ailhaud and colleagues (2006) claim that increased consumption of n-6 PUFAs, especially when combined with low intake of n-3 PUFAs, may promote development of excessive adipose tissue [86]. One clinical trial found that in elderly men fed a diet high in linoleic acid (LA, a n-6 PUFA), the mean body weight of the experimental group (n=393) increased while the mean body weight of the control group (n=389) decreased. Other studies have found that higher n-6 PUFA to n-3 PUFA intake ratios result in increased risk of several chronic diseases, including coronary heart disease, hypertension, type 2 diabetes, renal disease, rheumatoid arthritis, ulcerative colitis, Crohn's disease, and chronic obstructive pulmonary disease, many of which have independent associations with adiposity [93]. Other beneficial effects of n-3 PUFAs include improvement of platelet aggregation, serum triglyceride concentrations, and anti-arrhythmic effects. Some of these effects are directly related to reduced metabolic syndrome and obesity. Despite this, and despite independent connections between the metabolic syndrome and excess adiposity, the role of n-6 fatty acid intake in overweight and obesity is not confirmed nor well understood. Clearly, further studies are needed.

In India, n-6 PUFA intake has increased in recent years, especially in landlocked areas with little access to seafood [46]. While many studies recommend a n-6:n-3 ratio below 4:1 [93], the mean n-6:n-3 ratio in our study population was 24:1. Although n-6:n-3 intake ratio was not significantly associated with BMI or any outcome variables, our results indicate that n-6 intake may be associated with body weight in rural India. Considering the high intake of n-6 PUFAs in comparison to n-3 PUFAs and the wealth of data indicating the health benefits of n-3 PUFAs, food policies and health education programming aimed at increasing consumption of n-3 PUFAs would be beneficial. Such actions may also reduce prevalence of underweight by discouraging energy-dense and nutrition-poor diets in favor of those that are nutrition-dense and energy-adequate [94]

3.4.1.8.2 Animal fat intake

Animal fat intake (saturated fats in milk products and meat) was negatively associated with BMI in this study population. This trend conflicts with animal experiments showing that diets high in animal fats leads to obesity and insulin resistance [95]. Less research has been done in this area with humans. In adults, failing to control for factors such as physical activity or smoking may result in confounding bias. Some epidemiologic cross- sectional studies found associations between saturated fatty acid intake and BMI or other obesity outcomes [96,97,98]. Another cross-sectional epidemiology study found that obese children had higher intake of saturated fatty acids after controlling for physical activity and overall energy intake [99]. However, due to the cross-sectional nature and low sample size of these studies, it is difficult to reach any causative conclusions about the effects of animal fat intake on overweight and obesity. Therefore, although our results conflict with other studies, they also add to this debate and we encourage further research with larger sample sizes before making any broad conclusions about the effects of dietary fats on adiposity. We may suggest that certain authors, such as Gaiha et al. (2010) [69] are too hasty in their recommendations to limit saturated fats in favour of polyunsaturated fats.

This is the first cross-sectional epidemiological study, to our knowledge, to find significant linear associations between fatty acid intake and BMI while controlling for many extemporaneous risk factors. However, we found no significant association between n-6 PUFA and animal fat consumption and overweight, obesity class I, or obesity class II during the logistic regression analysis, while n-6 PUFA intake was associated with decreased odds of underweight. This may indicate that associations between fatty acid intake and BMI are driven by values within the underweight and normal range. In addition, average fat intake of the study population was well below values reported elsewhere in India [22] and also below recommendations for rural populations set out by the Indian National Institute of Nutrition [100], which may have skewed results. Further research is therefore needed in this field.

3.4.2 Limitations

Our study has a number of limitations. Most importantly, the cross-sectional nature of the study precludes the ability to distinguish causes from effects. BMI was used as a measure of adiposity instead of waist-to-hip ratio or triceps or subscapular skinfold thickness, which may be more valid methods of determining excess body fat and categorizing high-risk overweight and obesity [101]. However, BMI is more accurate when comparing individuals within the same ethnic group [101]. The choice to use more sensitive IOTF BMI cut-offs for determining overweight and obesity reduces the comparability of our data to previous studies in India. Several potential risk factors (e.g. family history of obesity, early childhood adiposity) were not assessed or controlled for since these data were not available. A validated FFQ was used for dietary assessments, and the validity of this approach has been documented by comparisons with more detailed methods [22]. However, FFQs are imperfect, are subject to recall bias, and do not reflect long-term dietary changes that may impact adiposity and disease risk [102].

3.5 Conclusion

The epidemic of overweight and obesity is a serious public health issue in rural India and raises concerns about the capacity of the health care system to cope with associated outcomes. Alarming prevalence data, including those in the current study, should be considered a call to action. A population-level strategy to prevent obesity is necessary. Such a strategy requires sound data to reduce inefficiencies and target risk factors that have the greatest impact. While further research is needed, results from our study suggest several risk factors that are associated with BMI, overweight, and obesity, and may inform public health programming. Risk factors identified by our study may be divided into two categories. One category is individual-level risk factors that may be targeted by behaviour changing programming. Such factors included physical activity, television usage, and dietary factors such as finger millet, oil, and fat consumption. The second category comprises society-level risk factors such as caste and socioeconomic status. These risk factors must be addressed on a macro- level through social welfare policy, public infrastructure and development programs. As India continues to develop, modernize, and urbanize, there is a need for strong education programs to ensure that populations are aware of the dangers of overweight, obesity, and related noncommunicable diseases.

REFERENCES

[1] Fuster V, Kelly BB, editors. Promoting Cardiovascular Health in the Developing World: A Critical Challenge to Achieve Global Health. Washington, DC: National Academies Press; 2010.

[2] World Health Organization. The global epidemic. IOTF report. 2010. Available at http://www.iaso.org/iotf/ obesity/obesitytheglobalepidemic/. Accessed 10 February 2015.

[3] International Institute for Population Sciences (IIPS). National Family Health Survey (NFHS-3). Ministry of Health and Family Welfare, Government of India. 2007. http://dhsprogram.com/pubs/pdf/frind3/00frontmatter00.pdf. Accessed 15 Jan 2015.

[4] Misra A, Singhal N, Sivakumar B, Bhagat N, Jaiswal A, Khurana L. Nutrition transition in India: Secular trends in dietary intake and their relationship to diet-related non-communicable disease. J of Diab. 2011; 3(4):278-92.

[5] Misra P, Upadhyay R, Misra A, Anand K. Review of the epidemiology of diabetes in rural India. J Diab Res Clin Pr. 2011; 92(3):303-11.

[6] Zaman M, Patel A, Jan S, Hillis GS, Krishnam Raju P P, Neal B, Chow CK. Socio-economic distribution of cardiovascular risk factors and knowledge in rural India. Int J Epidemiol. 2012;41:302-314.

[7] Mahadik SR, Deo SS, Mehtalia SD. Increased prevalence of metabolic syndrome in non-obese asian Indian-an urban-rural comparison. Metab Syndr Relat Disord. 2007;5:142–52.

[8] Razak F, Anand SS, Shannon H, Vuksan V, Davis B, Jacobs R, Teo KK, McQueen M, Yusuf S. Defining obesity cut points in a multiethnic population. Circulation. 2007;115:2111–8.

[9] Doak CM, Adair LS, Bentley M, Monteiro C, Popkin BM. The dual burden household and the nutrition transition paradox. Int J Obes. 2005; 29(1):129-36.

[10] Danaei G, Ding EL, Mozaffarian D, Taylor B, Rehm J, Murray CJL, et al. The preventable causes of death in the United States: comparative risk assessment of dietary, lifestyle, and metabolic risk factors. PLoS Med. 2009;6:e1000058.

[11] Ewing R, Shmid T, Killingsworth R, Zlot A, Raudenbush S. Relationship between urban sprawl and physical activity, obesity, and morbidity. Am J Health Promot. 2003;18(1):47-57.

[12] Kleiser C, Rosario AS, Mensink GBM, Prinz-Langenohl R, Kurth BM. Potential determinants of obesity among children and adolescents in Germany: results from the cross-sectional KiGGS study. BMC Public Health. 2009;9:46-54.

[13] Janssen I, Katzmarzyk PT, Boyce WF, Vereecken C, Mulvihill C, Roberts C, Currie C et al. Comparison of overweight and obesity prevalence in school-aged youth from 34 countries and their relationship with physical activity and dietary patterns. Obes Rev. 2005;6:123-132.

[14] Little M, Humphries S, Patel K, Dodd W, Dewey C. Factors associated with glucose tolerance, pre-diabetes, and type 2 diabetes in a rural community of south India: A cross sectional study. Diabetology and Metabolic Syndrome [Under Review]. 2016.

[15] Karthikeyan M, Jena D, Patel K, Khadka K, Devkota R, Samaratunga H et al. Baseline Survey in Project Sites: A Report as a Part of Revalorizing Small Millets in the Rainfed Regions of South Asia (RESMISA). India, Nepal, Sri Lanka and Canada: DHAN Foundation, Arthacharya Foundation, Local Initiatives for Biodiversity, Research and Development (LIBIRD) and Canadian Mennonite University. 2012.

[16] World Health Organization. WHO STEPS Surveillance Manual: The WHO STEPwise approach to chronic disease risk factor surveillance. 2005. http://apps.who.int/iris/bitstream/10665/43376/1/9241593830_eng.pdf?ua=1. Accessed 10 Dec 2014.

[17] International Institute for Population Sciences (IIPS). National Family Health Survey (NFHS-2). Mumbai, India: IIPS;2007.

[18] Ebrahim S, Kinra S, Bowen L, Andersen E, Ben-Shlomo Y, Lyngdoh T, Ramakrishnan L et al. The effect of rural-to-urban migration on obesity and diabetes in India: A cross-sectional study. PLoS Medicine. 2007;7(4):e1000268.

[19] Humphreys JS. Delimiting ‘rural’: implications of an agreed ‘rurality’ index for healthcare planning and resource allocation. Aust J Rural Health. 1998;6(4):212-216.

[20] Weinert C, Boik RJ. MSU Rurality index: Development and evaluation. Res Nursing Health. 1995;18:453-64.

[21] World Health Organization. Global Physical Activity Questionnaire (GPAQ) Analysis Guide. 2011. http://www.who.int/chp/steps/resources/GPAQ_Analysis_Guide.pdf. Accessed 10 November 2013.

[22] Sudha V, G, Sathya RM, Ganesan A, Mohan V. Reproducibility and validity of an interviewer-administered semi-quantitative questionnaire to assess dietary intake of urban adults in southern India. Int J Food Sci Nutr. 2006;57(7-8):481-93.

[23] Madras Diabetes Research Foundation. EpiNu® version 1.0. Chennai, India; 2007.

[24] Radhika G, Sathya RM, Ganesan A, Saroja R, Vijayalakshmi P, Sudha V et al. Dietary profile of urban adult population in South India in the context of chronic disease epidemiology (CURES-68). Public Health Nutr. 2011;1494:591-598.

[25] Chobanian AV, Bakris GL, Black HR, Cushman WC, Green LA, et al. The seventh report of the Joint National Committee on Prevention, Detection, Evaluation and Treatment of High Blood Pressure (JNC-7). JAMA. 2003;289:2560– 2571.

[26] World Health Organization. The Asia Pacific perspective. Redefining obesity and its treatment. World Health Organization. International Association for the study of Obesity and

International Obesity Task Force. Melbourne International Diabetes Institute; 2000.

[27] Microsoft Corporation: Redmond WA USA 1998-2009. [28] Census of India 2011 database. Government of India, Ministry of Home Affairs, Office of the Registrar General and Census Commissioner. 2011. http://www.censusindia.gov.in/2011census/C-series/C-13.html. Accessed 15 Jan 2015.

[29] StataCorp: College Station TX USA 1985-2013.

[30] Dohoo I, Martin W, Stryhn H. Methods in Epidemiologic Research. VER Inc: Charlottetown, PEI; 2012.

[31] Burke V, Beilin LJ, Simmer K, Oddy WH, Blake KV, Doherty D, Kendall GE et al. Predictors of body mass index and associations with cardiovascular risk factors in Australian children: a prospective cohort study. Int J Obes. 2005;29(1):15-23.

[32] Pramod Sing GC, Nair M, Grubesic RB, Connell FA. Factors associated with underweight and stunting in rural Terai of eastern Nepal. Asia-Pacific J of Public Health. 2009;21(2):144-152.

[33] Martinez-Gonzalez MA, Martinez JA, Hu FB, Gibney MJ, Kearney J. Physical inactivity, sedentary lifestyle and obesity in the European Union. Int J of Obesity. 1999;23:1192-1201.

[34] Agrawal S, Ebrahim S. Prevalence and risk factors for self-reported diabetes among adult men and women in India: findings from a national cross-sectional survey. Public Health Nutr. 2011;15(6):1065-1077.

[35] Misra R, Misra A, Kamalamma N, Vikram NK, Gupta S, Sharma S et al. Difference in prevalence of diabetes, obesity, metabolic syndrome and associated cardiovascular risk factors in a rural area of Tamil Nadu and an urban area of Delhi. Int J Diabetes Dev Ctries. 2011;31(2):82-90.

[36] Vijayakumar G, Arun R, Kutty VR. High prevalence of type 2 diabetes mellitus and other metabolic disorders in rural central Kerala. J Assoc Physicians India. 2009;57:563- 7.

[37] Florencio TM, Ferreira HS, de Franca AP, Cavalcante JC, Sawaya AL. Obesity and undernutrition in a very-low-income population in the city of Maceio, northeastern Brazil. Br J Nutr. 2001;86:277–284

[38] Steyn K, Bourne L, Jooste P, Fourie JM, Rossouw K, Lombard C. Anthropometric profile of a black population of the Cape Peninsula in South Africa. East Afr Med J. 1998;75:35–40

[39] Doak C, Monteiro C, Adair LS, Bentley ME, Popkin BM. Coexisting overweight and underweight within households is related to the nutrition transition. FASEB. 2000;14:A792.

[40] Du S, Lu B, Zhai F, Popkin BM. The nutrition transition in China: a new stage of the Chinese diet. In: Caballero B, Popkin BM, editors. The nutrition transition: Diet and disease in the developing world. London: Academic Press; 2002. p. 205-22.

[41] Kaur P, Rao SR, Radhakrishnan E, Ramachandran R, Venkatachalam R, Gupte MD. High prevalence of tobacco use, alcohol use and overweight in a rural population in Tamil Nadu, India. J Postgrad Med. 2011; 57(1):9-15.

[42] Hamilton C, Filardo G. The dangers of categorizing body mass index. European Heart Journal. 2006;27(23):2903-2904.

[43] Royston P, Altman DG, Sauerbrei W. Dichotomozing continuous predictors in multiple regression: a bad idea. Stat Med. 2006;15:127-141.

[44] Taylor JMG, Yu M. Bias and efficiency loss due to categorizing an explanatory variable. J Mult Anal 2002;83:248-263.

[45] Mamidi RS, Kulkarne B, Singh A. Secular trends in height in different states of India in relation to socioeconomic characteristics and dietary intakes. Food Nutr Bull. 2011;32(1):23-234.

[46] Shetty P. Nutrition transition in India. Public Health Nutr. 2002;5(1A):175-82.

[47] Preiss D. Thomas LE, Wojdyla DM, Haffner SM, Gill JMR, Yates T et al. Prospective relationships between body weight and physical activity: an observational analysis from the NAVIGATOR study. BMJ Open. 2015;5(8):e007901

[48] Hausenblas HA, and Symons Downs D. How much is too much? The development and validation of the exercise dependence scale. Psychol & Health. 2010;17(4):387-404.

[49] Iqbal BA. India's hungry and enslaved: Badar Alam Iqbal examines two major problems confronting India. New Zealand International Review. 2014;39(4):24-26.

[50] Ramachandran A, Snehalatha C, Baskar ADS, Mary S, Sathis Kumar CK, Selvam S et al. Temporal changes in prevalence of diabetes and impaired glucose tolerance associated with lifestyle transition occurring in the rural population in India. Diabetiologia. 2004;47:860-865.

[51] Little M, Humphries S, Patel K, Dewey C. Decoding the type 2 diabetes epidemic in rural India: patients' knowledge, explanatory models, and narratives. Med Anthro. 2016: In press.

[52] Government of India. Census of India 2011: Provisional Population Totals Urban Agglomerations and Cities. 2011. http://www.censusindia.gov.in/2011-prov- results/paper2-vol2/data_files/India2/1.%20Data%20Highlight.pdf. Accessed 10 Feb 2015.

[53] Samuel P, Antonisamy B, Raghupathy P, Richard P, Fall CHD. Socio-economic status and cardiovascular risk factors in rural and urban areas of Vellore, Tamilnadu, South India. Int J Epidemiol. 2012;41:1315-1327.

[54] Pandey R, Gupta R, Misra A, Sing V, Agrawal A, Dey S et al. Determinants of urban-rural differences in cardiovascular risk factors in middle-aged women in India: A cross-sectional study. Int J Cardiol. 2013;163:157-162.

[55] Joshi SR, Anjana RM, Deepa M, Pradeepa R, Bhansali A, Dhandania VK et al. Prevalence of dyslipidemia in urban and rural India: The INDIAB Study. PLOS One. 2014; 9(5):e96808.

[56] Deepa M, Pradeepa R, Rema M, Mohan A, Deepa R, Shanthirani S, Mohan V. The Chennai Urban Rural Epidemiology Study (CURES) – Study design and methodology. J App Phys India. 51:863-870.

[57] Office of Technology Assessment. Health care in rural America (OTA-H-434). 1990. https://www.princeton.edu/~ota/disk2/1990/9022/9022.PDF. Accessed 9 Nov 2015.

[58] Rousseau N. What is rurality? Occas Pap R Coll Gen Pract. 1995;71:1-4.

[59] Government of India. Census of India 2011: Provisional Population Totals Urban Agglomerations and Cities. http://www.census2011.co.in/data/village/644087-anchetty- tamil-nadu.html. Accessed 9 Nov 2015..

[60] Dewey R. The rural-urban continuum: real but relatively unimportant. Am J Sociol. 1960;66(1):60-66.

[61] Rourke J. In search of a definition of 'rural'. Can J Rural Med. 1997;2(3):113-115.

[62] Leduc E. Defining rurality: A general practice rurality index for Canada. Can J Rural Med. 1997;2:125-131.

[63] Faulkner HW, French S. Geographic Remoteness: Conceptual and measurement problems. Canberra Bureau of Transport Economics. 1983;54.

[64] Cloke PJ, Edwards G. Rurality in England and Wales: A replication of the 1971 index. Regional Studies. 1986;20:289-306.

[65] Patel V, Kleinman A. Poverty and common mental disorders in developing countries. Bulletin of the World Health Organization. 2003;81:609e-615.

[66] Mendenhall E, Shivashankar R, Tandon N, Ail MK, Venkat Narayan KM, Prabhakaran D. Stress and diabetes in socioeconomic context: A qualitative study of urban Indians. Soc Sci Med. 2012;75:2522-2529.

[67] Martinez JA. Body-weight regulation: causes of obesity. Proc Nutr Soc. 2000;59(3):337-345.

[68] Kinra S, Bowen LJ, Lyngdoh T, Prabhakaran D, Reddy KS, Ramakrishnan L et al. Sociodemographic patterning of non-communicable disease risk factors in rural India: a cross-sectional study. BMJ. 2010;341:c4974.

[69] Gaiha R, Jha R, Kulkarni VS. Obesity, affluence, and urbanization in India. ASARC working paper. 2010. https://crawford.anu.edu.au/acde/asarc/pdf/papers/2010/WP2010_10.pdf. Accessed 8 November 2014.

[70] Sobal J, Stunkard, AJ. Socioeconomic status and obesity: A review of the literature. Psychol Bull. 1989;105(2):260-275. Davidar P, Arjunan

[71] Davidar P, Arjunan M, Puyravaud JP. Why do local households harvest forest products? A case study from the southern Western Ghats, India. Biol Cons. 2008;141:1876-1884.

[72] Silori CS, Mishra BK. Assessment of livestock grazing pressure in and around the elephant corridors in Mudumalai Wildlife Sanctuary, South India. Biol Cons. 2001;10:2181-2195.

[73] National Readership Studies Council. NRS 2006: Key Findings. 2006. http://www.slideshare.net/targetseo/national-readership-studies-india-nrs-2006. Accessed June 17 2015.

[74] Radhakrishnan RR. Free TV sets distribution begins. The Hindu. http://www.thehindu.com/todays-paper/tp-national/tp-tamilnadu/free-tv-sets-distribution-begins/article3076310.ece. Accessed 16 June 2015.

[75] Electronics Corporation of Tamil Nadu. Free television scheme for people of Tamil Nadu. http://www.elcot.in/free_colortv.php. Accessed 16 June 2015.

[76] Kuriyan R, Bhat S, Thomas T, Vaz M, Kurpad, A. Television viewing and sleep are associated with overweight among urban and semi-urban South Indian Children. Nutr J. 2007;6:25.

[77] Brown W, Williams L, Ford JH, Ball K, Dobson AJ. Identifying the energy gap: Magnitudes and determinants of 5-year weight gain among midage women. Obes Res. 2004;13(8):1431-1441.

[78] Adinatesh KV, Prashanr RK. Prevalence of childhood obesity among school children in Karimnagar town. MRIMS J Health Sci. 2013;1(1):8-11.

[79] Bamshal M, Kivisild T, Scott Watkins W, Dixon ME, Ricker CE, Rao BB, et al. Genetic evidence on the origins of Indian caste populations. Genome Res. 2001;11:994- 1004.

[80] Locke AE, Kahali B, Verndt SI, Justice AE, Pers TH, Day FR, et al. Genetic studies of body mass index yield new insights for obesity biology. Nature. 2015;518:197-206.

[81] Ng M, Freeman M, Fleming T, Robinson M, Dwyer-Lindgren L, Thomson B et al. Smoking prevalence and cigarette consumption in 187 countries, 1980-2012. JAMA. 2014;311(2):183-192.

[82] Rani M, Bonu S, Hja P, Nguyen SN, Jamjoum L. Tobacco use in India: prevalence and predictors of smoking and chewing in a national cross sectional household survey. Tobacco Control. 2003;12:e4.

[83] Plurphanswat N, Rodu B. The association of smoking and demographic characteristics on body mass index and obesity among adults in the U.S., 1999-2012. BMC Obes. 2014;1:18.

[84] Jacobs DR, Gottenborg S. Smoking and weight: the Minnesota Lipid Research Clinic. Am J Public Health. 1981;71:391-396.

[85] Albanes M, Jones Y, Micozzi MS, Mattson ME. Associations between smoking and body weight in the US population: Analysis of NHANES II. Am J Public Health. 1987;77:439-444.

[86] Pednekar MS, Gupta PC, Shukla H, Hevert JR. Associations between tobacco use and body mass index in an urban Indian population: implications for public health in India. BMP Public Health. 2006;99:1-5.

[87] Kumar P, Mruthyunjaya, Dey MM. Long-term changes in Indian food basket and nutrition. Econ Polit Weekly. 2007;42(35):3567–3572.

[88] Ailhaud G, Massiera F, Weill P, Legrand P, Allesandri JM, Guesnet P. Temporal changes in dietary fats: Role of n-6 polyunsaturated fatty acids in excessive adipose tissue development and relationship to obesity. Prog Lipid Res. 2006;45:203-236.

[89] Willett WC. Dietary fat plays a major role in obesity: no. Obes Rev. 2002;3:59-68.

[90] Bray GA, Popkin BM. Dietary fat does affect obesity! Am J Clin Nutr. 1998;68:1157-73.

[91] Nelson LH, Tucker LA. Diet composition related to body fat in a multivariate study of 203 men. J Acad Nutr Diet. 1996;96(8):771-777.

[92] Tucker LA, Kano MJ. Dietary fat and body fat: a multivariate study of 205 adult females. The Am J Clin Nutr. 1992;56(4):616-622.

[93] Simopolous AP. Essential fatty acids in health and chronic disease. Am J Clin Nutr. 1999;70 Suppl 1:560-9.

[94] Caballero B. A nutrition paradox – underweight and obesity in developing countries. N Engl J Med. 2005;352(15):1515-1516.

[95] Buettner R, Scholmerich J. High-fat diets: Modeling the metabolic disorders of human obesity in rodents. Obesity. 2007;15(4):798-808.

[96] Romieu I, Willett WC, Stampfer MJ, Colditz GA, Sampson L, Rosner B et al. Energy intake and other determinants of relative weight. Am J Clin Nutr. 1988;47(3):406-412.

[97] Maron DJ, Fair JM, Haskell WL. Saturated fat intake and insulin resistance in men with coronary artery disease. Circulation. 1991;84:2070–2074.

[98] Dreon DM, Frey-Hewitt B, Ellsworth N, Williams PT, Terry RB, Wood PD. Dietary fat: Carbohydrate ratio and obesity in middle-aged men. Am J Clin Nutr. 1988;47:995- 1000.

[99] Gillis LJ, Kennedy LC, Gillis, AM, Bar-Or O. Relationship between juvenile obesity, dietary energy and fat intake and physical activity. Int J Obes. 2002;26(4):458- 463.

[100] National Institute of Nutrition. Dietary Guidelines for Indians: A Manual. Indian Council

of Medical Research. 2010. http://ninindia.org/DietaryguidelinesforIndians- Finaldraft.pdf. Accessed 15 February 2015.

[101] Gallengher D, Mariolein V, Sepu Alveda D, Pierson RN, Harris T, Heymsfield SB. How useful is body mass index for comparison of body fatness across age, sex, and ethnic groups? Am J Epidemiol. 1996;143:228-239.

[102] Bingham S, Luben R, Welch A, Ling Low Y, Tee Khaw K, Wareham N, Day N. Associations between dietary methods and biomarkers, and between fruits and vegetables and risk of ischaemic heart disease, in the EPIC Norfolk Cohort Study. Int J Epidemiology. 2008;37(5):978-987.

TABLES

Table 3.1: Descriptive, socio-economic, physical activity, and dietary characteristics of a sample of individuals in rural south India by category of BMI

Characteristic	Underweight (BMI<18.5 kg/m^2, n=84)	Normal (n=300)	Overweight (BMI ≥ 23.0 kg/m^2 and <25 kg/m^2, n=118)	Obesity Class I (BMI ≥ 25 kg/m^2 and < 30 kg/m^2, n=132)	Obesity Class II (BMI ≥ 30 kg/m^2, n=26)	P-value for trend$^+$
Descriptive characteristics						
Age	49.6±17.2	46.8±14.8	47.4±13.5	45.1±11.7	43.6±11.5	0.05
Women (%)	51.7	53.8	52.5	58.3	76.9	0.145
Waist to Hip Ratio	0.84±0.072	0.87±0.075	0.91±0.07	0.92±0.09	0.92±0.08	<0.001
Hypertension (%)	19.4%	25.8	40.7	38.9	50	<0.001
Rurality Index	0.04±1.1	-0.37±1.3	-0.86±1.32	-1.0±1.28	-1.95±1.0	<0.001
Current tobacco consumer (%)	50	40.5	34.7	31.5	7.7	<0.001
Socioeconomic and education characteristics						
Wealth index	9.7±3.9	10.7±4.6	11.3±4.8	12.3±5.0	13.5±5.6	<0.001
Vehicle ownership (%)	17.6	26.3	34.7	35.6	42.3	0.001
Television ownership (%)	78.3	88.3	95.8	95.5	96.1	<0.001
Pucca housing (%)	4.5	12.2	15.3	22.7	47.1	<0.001
In-house tap water (%)	4.5	7.6	6.7	10.6	30.8	<0.001
Education (maximum grade achieved)	2.1±3.5	3.1±4.4	3.2±4.2	3.7±4.5	4.4±4.8	0.007
Physical activity characteristics						
Physical Activity (h/day of moderate physical activity)	4.0±3.4	4.4±3.7	4.3±4.0	3.2±3.4	1.1±2.3	<0.001
Sitting time (h/day)	4.2±2.6	4.3±4.3	4.3±2.5	5.0 ±2.8	6.2±2.8	<0.001
Television time (h/day)	1.3±1.35	1.3±1.2	1.6±1.2	1.8±1.37	2.1±1.6	<0.001
Labour occupation (%)	63.6	64.4	56.7	51.6	38.5	0.012
Dietary characteristics						
Current alcohol consumer (%)	49.4	46.2	52.5	44.7	34.6	0.432
Total energy intake (kcal/day)	2390±758	2365±724	2439±625	2440±702	2031±585	0.11
Carbohydrates (g/1000 kcal)	183±14	181±15	177±15	177±13	170±8	<0.001
Protein (g/1000 kcal)	25.5±1.9	25.7±2.0	25.5±1.8	25.9±1.7	26.2±1.8	0.26
Total fat (g/1000 kcal)	18.2±5.3	19.2±5.3	20.6±4.8	21.2±5.1	23.6±2.9	<0.001
Dietary fibre (g/1000 kcal)	34.4±12	32.7±13	29.3±11	29.6±11	23.1±7.7	<0.001
Dairy products (g/1000 kcal)	85.2±77	74.1±64	79.7±62	87.1±67	102.5±66	0.11
Pulses and legumes (g/1000 kcal)	24.2±11	27.6±12	29.6±12	29.4±12	30.7±11	0.01
Meat and poultry (g/1000 kcal)	2.93±3.8	3.3±4.1	2.8±3	3.3±4.6	3.7±3.4	0.61
Fruits and vegetables (g/1000 kcal)	63.1±41	75.6±46	86.6±58	84.3±50	87.0±37	<0.001
Refined grains (g/1000 kcal)	135±76	153±83	178±90	165±75	154.6±55	<0.001

Abbreviations: BMI, body mass index; kcal, kilocalories

$^+$P-values are for differences in means and proportions of each characteristic between diagnostic categories using one-way analyses of variance and Pearson's chi-squared tests, respectively

Table 3.2: Factors associated with body mass index for a sample of adults (>19 years) in rural south India in a multivariable linear regression model

Variable	Coefficient	Standard Error	P-value^{+}
Constant	19.48	0.57	<0.001
Physical Activity (h/day of moderate activity)	-0.085	0.040	0.034
Wealth index	0.14	0.031	<0.001
Livestock ownership (Y/N)	-0.76	0.30	0.013
Animal fat intake (g/1000 kcal)	-0.060	0.026	0.023
n-6 PUFA intake (g/1000 kcal)	0.11	0.039	0.022
Television time (h/day)	0.34	0.11	0.003
Tobacco consumption (Y/N)	-0.95	0.29	0.001
Rurality index	-0.76	0.12	<0.001
High caste (Y/N)	1.64	0.49	0.001

Abbreviations: PUFA, polyunsaturated fatty acids

$^{+}$P-values are for coefficients in fully-adjusted multivariable linear regression model

Table 3.3: Factors associated with overweight, class I and class II obese for a sample of adults in rural south India (>19 years) in a multinomial multivariable logistic regression model[+]

Variable	Overweight* OR (95% CI)	Obesity Class I** OR (95% CI)	Obesity Class II*** OR (95% CI)
Physical Activity (h/day of moderate physical activity)	1.02 (0.96, 1.08)	0.94[b] (0.88, 0.99)	0.75[a] (0.62, 0.92)
Wealth index	1.02 (0.97, 1.07)	1.07[a] (1.03, 1.12)	1.09[b] (1.00, 1.17)
Own a television (Y/N)	2.88[b] (1.08, 7.67)	2.19 (0.81, 5.87)	1.17 (0.13, 10.8)
Television time (h/day)	1.06 (0.90,1.26)	1.19[b] (1.01, 1.39)	1.22[d] (0.13, 10.8)
High caste (Y/N)	2.37[b] (1.21, 4.67)	3.54[a] (1.90, 6.60)	4.62[b] (1.22, 17.49)
Rurality index	0.70[a] (0.52, 0.83)	0.69[a] (0.59, 0.82)	0.41[a] (0.26, 0.63)
Tobacco consumer (Y/N)	0.80 (0.52, 1.23)	0.75[d] (0.48, 1.16)	0.15[b] (0.035, 0.68)

Abbreviations: BMI, body mass index; OR, odds ratio; CI, confidence interval
[+]non-overweight (<23 kg/m^2) used as referent
*BMI ≥ 23.0 kg/m^2 and <25 kg/m^2, n=118, **BMI ≥ 25 kg/m^2 and < 30 kg/m^2, n=132, ***BMI ≥ 30 kg/m^2, n=26
[a]significant to p<0.01, [b]significant to p<0.05, [c]tendency to p<0.1, [d]tendency to p<0.2

Table 3.4: Factors associated with underweight for a sample of adults (>19 years) in rural south India in a multivariable logistic regression analysis[+]

Variable	Underweight* OR (95% CI)
Wealth index	0.93[a] (0.90, 0.98)
Rurality index	1.48[a] (1.24, 1.56)
n-6 PUFA (g/day)	0.98[b] (0.95, 0.99)
Tobacco consumption (Y/N)	0.77[a] (0.43, 1.38)

Abbreviations: BMI, body mass index; PUFA, polyunsaturated fatty acids
[+]non-underweight (BMI ≥18.5 kg/m^2) used as referent
*BMI <18.5 kg/m^2, n=169
[a]significant to p<0.01, [b]significant to p<0.05

CHAPTER FOUR:

FACTORS ASSOCIATED WITH GLUCOSE TOLERANCE, PRE-DIABETES, AND TYPE 2 DIABETES IN A RURAL COMMUNITY OF SOUTH INDIA: A CROSS-SECTIONAL STUDY[1]

ABSTRACT

Background: India's national rural prevalence of type 2 diabetes has quadrupled in the past 25 years. Despite the growing rural burden, few studies have examined putative risk factors and their associations with glucose intolerance and diabetes in rural areas. We undertook a cross-sectional study to determine the prevalence of impaired fasting glucose (IFG), impaired glucose tolerance (IGT), and type 2 diabetes in a rural area of south India. In addition, we assessed factors associated with glucose intolerance and type 2 diabetes in multivariable linear and logistic regression analyses.

Methods: We sampled one adult from 8% of households in 17 villages using a randomized household-level sampling technique. Each participant undertook a questionnaire that included basic descriptive information and an assessment of socioeconomic position, physical activity, and dietary intake. Height, weight, waist and hip circumference, and blood pressure measurements were taken. An oral glucose tolerance test was used to determine diabetes status. We used backward stepwise logistic model building techniques to determine associations between several putative factors and glucose tolerance status.

Results: 753 participants were included in the study. The age and sex-standardized prevalence of IFG was 3.9%, IGT was 5.6%, and type 2 diabetes was 10.8%. Factors associated with type

---

[1] *A version of this article is published as:* Little, M., Humphries, S., Patel, K., Dodd, W., & Dewey, C. (2016). Factors associated with glucose tolerance, pre-diabetes, and type 2 diabetes in a rural community of south India: a cross-sectional study. *Diabetology & Metabolic Syndrome*, *8*(1), 21.

2 diabetes after adjusting for multiplied variables and potential confounders included physical activity [OR 0.81], rurality [OR 0.76], polyunsaturated fat intake [OR 0.94], body mass index [OR 1.85], waist to hip ratio [OR 1.62], and tobacco consumption [OR 2.82].

Conclusion: Our study contributes to the growing body of research suggesting that diabetes is a significant concern in rural south India. Associated risk factors should be considered as potential targets for reducing health burdens in India.

4.1 Background

Type 2 diabetes mellitus (diabetes) is an international pandemic with high morbidity and mortality and a large economic impact. An alarming 80% of the global burden lies in low and middle-income countries (LMICs) [1]. While in urban areas of LMICs, diabetes is recognized as a public health priority and is often well studied; recent prevalence data suggest that diabetes is an increasing problem among rural populations as well [2]. In India, while regional differences exist, national rural prevalence has quadrupled in the past 25 years [3]. A recent large-scale study in a rural community in south India found a diabetes prevalence of 7.8%. That same study found a prevalence of pre-diabetes (impaired fasting glucose and/or impaired glucose tolerance) of 7.1%, representing a population at heightened risk of conversion to overt diabetes [4]. Despite evidence indicating a growing rural burden of diabetes, few studies have examined putative risk factors and their relationship with glucose intolerance and diabetes in rural areas. ‘Modernization’ and ‘globalization’ are often implicated, but precise pathways of causation are unclear and understudied [2]. Moreover, rising national prevalence of diabetes is often attributed to urbanization, which results in a disproportionate focus on urban areas and ignores the epidemiological environment of rural regions [3]. Given the inherent diversity of India in terms of livelihoods, ethnicity, culture, food habits, and lifestyle, there exists a need for research on diabetes and risk factors from different regions across the entire urban/rural continuum to broaden our understanding of the epidemic [5].

We report here the findings of a cross-sectional surveillance study in a rural population of northern Tamil Nadu. The study had two principal objectives. First, to establish prevalence of impaired fasting glucose (IFG), impaired glucose tolerance (IGT), and diabetes in the research site. Second, to assess associations between diabetes risk and a number of anthropometric, socioeconomic, lifestyle, and dietary factors through multivariable linear and logistic regressions. Such analyses identify potential risk factors that can be further analyzed in case-control and cohort studies. Identifying risk factors of type 2 diabetes is crucial in resource prioritization and allocation for prevention and surveillance programs in India, especially considering the shortage of personnel and resources in rural areas.

4.2 Methods

4.2.1 Ethics, consent, and permissions

We obtained clearance for the study from a Canadian university ethics board. Permission for the study was granted by the High Commission of India in Ottawa, Canada. Upon arrival to the research site, and prior to the recruitment process, we approached local authorities (*panchayat* councils, local police officials, and hospital medical staff) and sought and obtained permission to carry out the study. Informed verbal consent to participate in the study was obtained from all participants prior to their enrollment.

4.2.2 Sample and study design

The sampling frame consisted of the entire adult population (>19 years old) of two rural panchayat wards (Anchetty panchayat and Madakkal panchayat), in the Krishnagiri District of Tamil Nadu. The region is comprised of several small villages surrounding the central market village of Anchetty. All villages within the sampling area were included in the study. We mapped each village, numbered the houses consecutively, and then randomly selected 8% of households from which to sample one adult individual. Our target was to sample 800 participants, based on a sample size calculation with an estimated type 2 diabetes prevalence of 8%, a precision of 0.02, and a confidence of 95%. Upon approaching a household, we employed WHO's Kish method to recruit an individual for the study [6]. If an individual declined to participate, we removed them from the household list and employed the Kish method again. If all adults in the household refused to participate, we approached a neighbouring household and repeated the process. Upon receiving consent, we collected basic demographic details, including age, sex, education, and occupation.

Socioeconomic status (SES) was assessed with a wealth index using a subset of 13 of 29 questions taken from the Standard of Living Index used by the 2nd round of the National Health and Family Survey (NFHS-2) (Table A1.1, Appendix 1) [7]. We selected those questions believed to be most relevant for our study population, including both household and village-level characteristics. Each attribute was weighted to give a maximum score of 41. Weights of items were developed by the International Institute of Population Sciences in India based on *a priori* knowledge about the relative significance of the items in determining SES [8]. Due to the rural subsistence nature of the local economy, this asset-based score is considered a more appropriate indicator of SES than education, income, or occupation [8].

We assessed dietary patterns using a validated interviewer-administered semi-quantitative food frequency questionnaire (FFQ) [9]. Individuals were asked to estimate the frequency of consumption (number of times per day/week/month/year) and usual serving size of 223 dishes and food items in the FFQ. A 'food atlas' with photographs was used as a visual prompt for foods and serving sizes. FFQ data were analyzed using EpiNu®, a software program that combined frequency of food consumption with corresponding nutrition information to provide detailed data on caloric consumption and average daily macro- and micronutrient intake [10]. Detailed descriptions of this FFQ and data on reproducibility and validity, including a comparison of FFQ estimates to 24-hr dietary recalls, have been published elsewhere [9]. All dietary variables except energy intake (kcal/day) were scaled to grams per 1000 kcal to account for differences in energy intake between participants.

Physical activity was assessed using the WHO Global Physical Activity Questionnaire (GPAQ) [11]. The GPAQ evaluates individuals' physical activity behavior in four domains: work, travel, and recreation, and sedentary time. The GPAQ was paired with locally relevant photographs depicting 'moderate', and 'vigorous'-intensity work and recreation activities. Physical activity scores were calculated using WHO's GPAQ Analysis Guide, which provided a total measure of Metabolic Equivalent (MET) minutes per week based on amount of time spent performing moderate and vigorous physical activity [11]. We scaled values to hours/day of moderate physical activity for ease of interpretation. Sedentary time was calculated as the number of hours spent sitting per day, including time spent relaxing, watching television, and performing sedentary work duties (e.g. desk work). Television time was assessed as hours per day spent watching television.

All previous epidemiology studies in India known to the authors define households as either rural or urban based on a dichotomous typology, which fails to adequately capture the variability inherent in the urban/rural continuum [12]. In order to better capture rurality, we created a rurality index based on Weinert and Boik's (1995) and adapted for use in India [13]. The index was generated by summing the standardized values of (1) distance to primary health center (in kilometers, assigned half weight), and (2) number of households in home village (assigned full weight). Values were standardized to a mean of zero and a standard deviation of one. The rurality index was therefore a unit less quantitative value assigned to each individual, with a higher value indicating a combination of a greater degree of isolation and a lower population density of household location.

Height, weight, waist circumference, and hip circumference measurements were taken by a doctor or nurse using standardized techniques [14]. We calculated body mass index (BMI) and waist-to-hip circumference ratios (WHR). Blood pressure was recorded using a portable OMRON BP-760 electronic blood pressure machine (Omron Healthcare, Hoofddorp, Netherlands). We took two measurements within 5 minutes on the right arm in the sitting posture, and the mean of the two was taken as blood pressure.

Glucose tolerance and diabetes status was determined using an oral glucose tolerance test [15]. After an 8-hr minimum overnight fast, we measured fasting capillary blood glucose (CBG) using a One Touch Ultra glucometer (Johnson & Johnson, Milpitas, CA, USA). Oral glucose (82.5 g glucose dissolved in 250 ml water, equivalent to 75 g anhydrous glucose) was administered and consumed within 5 minutes. A 2-hour post load CBG was then collected [14]. CBG was adopted instead of venous plasma glucose estimations due to unavailability of quality-controlled laboratories and difficulties associated with transporting refrigerated blood samples to a central laboratory. Studies have also found higher nonresponse rates associated with venous blood draws [16,17]. Priya et al. (2011) compared CBG to venous plasma glucose estimation and determined the Pearson’s correlation coefficient was 0.681 ($p<0.001$) in the fasting state and 0.897 ($p<0.001$) 2 hours post-load [16]. Thus, CBG was viewed as an accurate and acceptable alternative to venous plasma glucose estimation for diabetes screening.

4.2.3 Definitions

High blood pressure was defined as an individual with systolic blood pressure 140 mmHg or more and diastolic blood pressure 90 mmHg or more [18]. Diabetes was defined as individuals diagnosed by a physician who could provide proof of diagnosis and/or those who had a fasting CBG ≥7 mmol/L (≥126 mg/dl) and/or a 2 hr post prandial CBG value ≥12.2 mmol/L (≥220 mg/dL) [15,19]. Impaired fasting glucose (IFG) was defined as a fasting CBG ≥6.1 mmol/L (≥110 mg/dL) and <7 mmol/L (<126 mg/dL) and a 2 h post-glucose value <8.9 mmol/L (<160 mg/dL) [15]. Impaired glucose tolerance (IGT) was defined as a fasting CBG <7 mmol/L and a 2 h post glucose CBG ≥8.9 mmol/L (≥160 mg/dL) but <12.2 mmol/L (220 mg/dL) [15]. Pre-diabetes was defined as having either or both IFG and IGT [19]. Underweight was defined as BMI<18.5 kg/m^2, overweight was defined as BMI ≥ 23.0 kg/m^2 but <25 kg/m^2, obesity class I was defined as BMI ≥ 25 kg/m^2 and < 30 kg/m^2, and obesity class II was defined as BMI ≥ 30 kg/m^2 [20]. Smoking status was categorized as 'nonsmoker' or 'current smoker'. Tobacco consumers were defined as either or both current smokers or current consumers of *paan* (smokeless tobacco).

4.2.4 Statistical analysis

We identified outliers, cleaned the data set, and completed summary statistics in Microsoft Excel 2010 (Redmond, WA, USA). All other statistical analyses were performed in STATA version 13.0 (College Station, TX, USA) [21]. Prevalence estimates were age- and sex-standardized using state-level age and sex data from the 2011 national census [22]. In separate models, univariate interactions between sex and glucose tolerance were analyzed. There were no significant associations between sex and outcome variables, and we therefore present the results for men and women combined. We calculated mean values of descriptive characteristics, socioeconomic variables, and dietary intake across categories of glucose tolerance, including normal, pre-diabetes, newly-diagnosed diabetes, and pre-diagnosed diabetes. Dietary variables were scaled to grams per 1000 kcal energy intake. Values were expressed as the mean+/-SD or percentages. One-way analysis of variance (for continuous variables) and a Pearson's X^2 test (for binary variables) were used to test differences across outcome groups.

We employed a backward stepwise model-building process to build two linear regression models assessing the associations between putative risk factors and 2-hr post- prandial CBG and fasting CBG. All factors were first analyzed in univariate linear regressions (see Appendix 2 for full list of factors). Variables with significant associations at p-value<0.2 in univariate analyses were included in an initial multivariable linear regression model. We then methodically eliminated non-significant variables (using a p-value cut-off of 0.05) from the multivariable model, assuming a lack of confounding if coefficients of all remaining variables did not change by more than 20% after removal of the potential confounder. Quadratic terms and interaction terms were assessed if there was a biological or practical reason to believe they may be significant. BMI and WHR datasets were standardized to a mean of zero and standard deviation of one for ease of comparability. Where linear regressions violated the assumptions of linear models, including normality of residuals and homoscedasticity, various outcome transformations were tested using the Box Cox function in STATA. Following this, models were adjusted if necessary [23]. If no transformations improved the assumptions of the model, we used robust standard errors when assessing the significance of each predictor, as suggested by Pires and Rodrigues (2007) [24].

In a second step, a multivariable multinomial logistic regression model was fitted to examine associations between putative risk factors and pre-diabetes and newly- diagnosed diabetes (i.e. those individuals diagnosed by our study). Normoglycemic individuals were the referent group. Individuals with pre-diagnosed diabetes were excluded to reduce potential reverse causation (i.e. behavioural changes resulting from diagnosis). We employed a backward stepwise model-building process that closely mirrored the methods described above. All putative risk factors were analyzed first in univariate logistic analyses and included in the initial multivariable model if an association existed (using a cut-off of $p<0.2$). Variables were eliminated if, in the final model, they were not associated with either pre-diabetes or diabetes (using a cut-off of $p<0.05$). Confounders were identified if they altered remaining coefficients by greater than 20% after their removal from the model. If a variable was identified as a confounder, it was forced into the final model.

4.3 Results

Of the 812 individuals recruited for the study, 753 participated (341 men and 412 women), of whom 752 (92.6%) completed an FFQ and 749 (92.2%) consented to blood sampling. Response rate was 87.4% among men and 99.2% among women ($p<0.05$). Disparity in the response rate was primarily due to migration among local men and thus unavailability at the time of sampling. The mean age (±SD) was 47 ±14.7 and the literacy rate was 35.1%. The unadjusted prevalence of diabetes was 11.7%, of which 56.4% were previously undiagnosed. The overall age and sex-standardized prevalence of diabetes was 10.8%. Age and sex-standardized prevalence of IFG was 3.9% and IGT was 5.6%, and overall standardized prevalence of pre-diabetes was 9.5%. None of the individuals with pre-diabetes had been previously diagnosed as such.

Baseline characteristics for the study population by diagnostic category are displayed in

Table 4.1. A significant difference was seen across categories in several descriptive characteristics and wealth attributes. However, the average wealth index and most dietary variables were not significantly different between diagnostic categories. Energy intake was significantly lower for individuals with diagnosed type 2 diabetes, perhaps indicating lower energy requirements (due to lower rates of physical activity), or post-diagnosis changes in diet due to doctor recommendations.

In the final multivariable linear regression model, several factors were associated with post-prandial CBG (Table 4.2). BMI and waist-to-hip ratio were positively associated with 2-hr CBG. Physical activity, rurality index, and intake of polyunsaturated fatty acids were negatively associated with 2-hr CBG. The untransformed model was heteroscedastic using a Cook-Weisberg test and lacked normality of standardized residuals using a Shapiro-Wilk statistic. We used a negative inverse transformation on the outcome variable, which solved the heteroscedasticity problem but residuals still lacked normality. We therefore used robust standard errors when assessing the significance of each predictor [24]. The adjusted R-squared value for the final model was 0.182.

In the final multivariable regression model, BMI, WHR, and tobacco consumption were positively associated with fasting CBG, while higher physical activity was associated with lower fasting CBG (Table 4.3). The untransformed model was heteroscedastic and lacked normality of standardized residuals. Using the Box Cox function in STATA and testing various transformations yielded no improvement. We therefore present the original untransformed model with robust standard errors [24]. The adjusted R-squared value for model two was 0.10. [Insert Table 3 here]

The following variables were associated (p-value<0.05) with pre-diabetes (IFG and/or

IGT) in univariate logistic regression analyses: standardized BMI [OR 1.62, 95% CI: 1.25, 2.10], standardized WHR [OR 1.55, 95% CI: 1.20, 2.01], physical activity [OR 0.90, 95% CI: 0.84, 0.98], rurality index [OR 0.67, 95% CI: 0.56, 0.79], sedentary time [OR 1.09, 95% CI: 1.01, 1.20], TV time [OR 1.21, 95% CI: 1.02, 1.45], hypertension [OR 1.88, 95% CI: 1.11, 3.19], livestock ownership [OR 0.55, 95% CI: 0.32, 0.94], family history of diabetes [OR 3.1, 95% CI: 1.53, 6.27], pucca house [OR 2.11, 95% CI: 1.11, 4.03], and fat intake [OR 0.92, 95% CI: 0.86, 0.99].

The following variables were associated with newly-diagnosed type 2 diabetes in univariate logistic regression analyses: age [OR 1.02, 95% CI: 1.00, 1.04], standardized BMI [OR 2.18, 95% CI: 1.65, 2.89], standardized waist-to-hip ratio [OR 2.02, 95% CI: 1.53, 2.65], physical activity [OR 0.78, 95% CI: 0.70, 0.87], rurality index [OR 0.71, 95% CI: 0.60, 0.85], sedentary time [OR 1.20, 95%CI: 1.09, 1.32], tobacco consumption [OR 2.08, 95% CI: 1.16, 3.71], in-house tap water [OR 2.5, 95% CI: 1.10, 5.71], hypertension [OR 2.8, 95% CI: 1.55, 4.95], livestock ownership [OR 0.45, 95% CI: 0.24, 0.86], and Muslim religion [OR 3.2, 95% CI: 1.03, 10.11].

After multivariable adjustment, several risk factors were associated with odds of pre-diabetes and newly-diagnosed diabetes (Table 4.4). Physical activity was associated with lower odds of pre-diabetes and diabetes. Family history of diabetes was associated with increased odds of pre-diabetes but not diabetes. Body mass index and waist-to-hip ratio were both independently associated with increased odds of type 2 diabetes. Higher rurality indices were associated with lesser odds of both pre-diabetes and diabetes. Tobacco consumption was associated with increased odds of type 2 diabetes. Intake of polyunsaturated fatty acids (PUFA) was associated with decreased odds of pre-diabetes and diabetes. PUFA consumption also confounded the association between family history and both pre-diabetes and diabetes, based on a change in coefficient of greater than 20% after its removal from the model. This confounding effect suggests that there may be an interaction with family history, possibly due to household clustering of dietary factors.

4.4 Discussion and Conclusion

The age- and sex-standardized prevalence of type 2 diabetes in the research site was 10.8%, which is one of the highest recorded prevalence estimates in rural India [3]. Vijayakumar et al. (2009) found higher prevalence of diabetes in a rural region of neighbouring Kerala based on fasting plasma glucose [25]. Chow et al. (2006) also found a higher prevalence in a rural area of neighbouring Andhra Pradesh, however the sample population comprised only of individuals >30 years of age [26]. Similar prevalence estimates have been found in peri-urban villages in Tamil Nadu [27]. All recent cross-sectional studies in rural Tamil Nadu found prevalence between 5.1 and 8.4%, slightly lower than the current study [19,28,29]. High prevalence in our sample may be indicative of local disparities and/or a continued increase of rural diabetes as predicted by Misra et al. (2011) [3]. Our study adds to the growing body of evidence suggesting that diabetes is no longer confined to urban areas of India and is a serious concern in rural regions as well. This is particularly troubling considering over 70% of the population of India lives in rural regions and these areas are often compromised by poverty and poor access to health care services [30].

Only 43.6% of individuals with diabetes were previously diagnosed. Of those who were undiagnosed, 90% did not previously know of the disease. This exposes a low diagnosis rate and a lack of knowledge about diabetes. The ratio of known to newly diagnosed diabetes was similar to a recent study in rural Tamil Nadu conducted by Anjana et al. (2011) (53%

diagnosed) [19], but markedly lower than a different large- scale cross-sectional study by Misra et al. (2011) (75% diagnosed) [32], perhaps indicating a low level of awareness of diabetes among the study population or discrepancies in the coverage of screening programs.

Age and sex-standardized prevalence of impaired fasting glucose and impaired glucose tolerance were 3.9% and 5.6% respectively, which sum to a pre-diabetes prevalence of 9.5%, similar to other recent studies in rural Tamil Nadu [19,28,31]. Balagopal et al. (2008) found a higher prevalence of pre-diabetes (13.5% based on fasting glucose only), potentially indicating regional disparities [29]. Fifty percent of individuals with pre- diabetes will develop overt diabetes within 10 years [32]. Consequently, high rates of pre-diabetes expose the potential for a continued rise of diabetes in the coming years, which may be of particular concern for already-overburdened healthcare systems in rural areas.

Previous studies have reported on various causes of type 2 diabetes in India, including urbanization, the ‘nutrition transition’, decreased physical activity, and emotional stress [33]. The changing dietary profile of Indians has received attention recently, most notably increased consumption of western foods and the rapid decline of traditional coarse cereals [34,35]. However, to our knowledge, this is the first cross- sectional study to assess associations between a wide range of dietary and lifestyle risk factors with diabetes outcomes in a rural area. While other studies have attempted to correlate risk factors with diabetes outcomes, most have been in an urban environment [36,37], only included self-reported diabetes [38], or failed to account for multiple variables and confounders in a multivariable statistical model [39,40,41]. This research is therefore important to elucidate the unique epidemiological environment of rural areas and identify the distinct factors associated with rural diabetes. While, due to the cross-sectional nature of the study, we are unable to determine causality, we attempted to minimize reverse causality associations by excluding pre-diagnosed diabetics from all models.

We found that higher physical activity was associated with lower post-prandial CBG, lower fasting CBG, and lesser odds of diabetes [OR 0.79]. This finding is consistent with previous research on the protective effects of physical activity against obesity, cardiovascular disease, and the metabolic syndrome [42]. The associations remained even after controlling for anthropometric measures, indicating that physical activity may have a direct impact on risk of diabetes apart from its association through overweight or obesity, which have been previously established [43].

Higher body mass index (BMI) and waist-to-hip ratio (WHR) were independently associated with higher post-prandial CBG, fasting CBG, and greater odds of diabetes. While overweight and obesity have been substantiated as risk factors for cardiovascular disease and the metabolic syndrome [44,45], ours is the first cross-sectional study in rural India to identify significant associations with BMI and WHR independent of each other. Currently, there is debate as to whether BMI or WHR ratio is better at conferring risk of non-communicable diseases [46]. Some recent studies have found that the association between BMI and diabetes becomes non-significant when adjusting for WHR and other variables, indicating that WHR is a better predictor of risk for Asian populations [47,48,49]. By contrast, a meta-analysis by Vazquez et al. (2005) found no significant difference in the abilities of BMI and WHR to predict incident diabetes, however they did find regional differences in pooled risk ratios, indicating disparity due to ethnicity [46]. In our analysis, both BMI and WHR were significant in all multivariable models and coefficients and ORs did not differ significantly. We therefore suggest that general obesity (BMI) and central obesity (WHR) may both be important risk factors for diabetes among Indian populations and should be considered independently and concurrently in research and clinical settings [50].

Tobacco (smoking and/or smokeless) use was prevalent among 48.7% of men and 31% of women. This corresponds with most previous studies that have found higher rates of use among men than women in India, but popularity differs between regions [51]. Tobacco use was associated with higher fasting CBG and greater odds of diabetes. Smoking has long been associated with glucose intolerance and diabetes. A systematic review found that of 25 studies, all but one identified a positive association between smoking and diabetes [52]. Cohort studies have also found a dose-response relationship between cigarettes smoked per day and incidence of diabetes [53,54]. Smokeless tobacco use among the study population is also concerning. A study in Sweden showed that smokeless tobacco users were three times more likely to develop type 2 diabetes than tobacco non-users [55]. In addition, most users in India mix smokeless tobacco with betel nut (*areca catechu*), which is independently associated with risk of diabetes [56]. With over one-third of the study population currently consuming tobacco, its contribution to chronic disease burdens cannot be underestimated. Reducing tobacco consumption must form an integral component of all prevention programs for diabetes, cardiovascular disease, cancers, and other non-communicable diseases [57].

Urban status is associated with diabetes risk in India [8,28,58]. Previous population-based chronic disease studies in India have maintained the dichotomous urban and rural definitions employed by Census India [59]. Dichotomous typology oversimplifies the urban/rural continuum and fails to capture the range of variation within rural areas [12]. While the entire study population was classified as ‘rural’ as per the Census Indian definition, we aimed to examine the variability within the study region by employing a rurality index. Surprisingly, rurality was one of the strongest predictors of diabetes risk outcomes. Lower rurality was associated with higher post-prandial CBG and higher odds of pre-diabetes and diabetes. This indicates that urban and semi-urban lifestyles, diets, and cultures may prevail with proximity to the market village and size of home village, and in turn may impact an individual's risk of diabetes. This is an important finding, as it demonstrates that by dichotomizing urban and rural status, previous studies have indeed failed to account for the nature of rurality as a continuum. We therefore recommend that researchers examine the rural/urban interface more closely, not only in population health studies, but also keeping in mind good health policy.

An interesting finding was the association between intake of polyunsaturated fats and diabetes outcomes. Polyunsaturated fatty acid intake appeared to confound the association between family history and both pre-diabetes and newly-diagnosed diabetes, likely due to clustering of dietary intake variables within households. We must therefore be careful in interpreting these variables in the regression models. Nevertheless, intake of polyunsaturated fatty acids was associated with a lower fasting CBG and lesser odds of pre-diabetes and diabetes. This was the only dietary factor that had a significant association with an outcome in any of the final multivariable models. Polyunsaturated fats are primarily found in natural vegetable oils, whole grains, nuts, seeds, and fish. While more research is needed in this area, this finding corresponds with a review study done by Hu et al. (2001), who concluded that substituting unhydrogenated unsaturated fats for saturated fats and trans-fats could lower risk of diabetes and other chronic diseases [60]. Apart from this study, little research has examined the association between dietary fat intake and diabetes. Results suggest that further investigations that better control for household clustering of both genetic and dietary factors are necessary. The lack of results showing significant associations between dietary variables and diabetes outcomes is interesting, especially considering the overwhelming evidence of the importance of dietary risk factors in determining risk of obesity, diabetes, and the metabolic syndrome [3,5,8,33,35,36,38,61]. This may indicate limitations in the ability of the FFQ to adequately assess dietary factors due to recall bias, interviewer bias, or location-specific anomalies. However, it is more likely that the data reflect a lack of sufficient variability in the rural diet to adequately assess the associations between dietary intakes and glucose tolerance within the study population. This is an important finding, as it may indicate that, while dietary changes are driving the type 2 diabetes epidemic in other locations, such as urban India, the rising rural prevalence of diabetes is due to other risk factors, such as physical activity, rising obesity, and genetic predisposition. Alternatively, individual dietary intakes may be changing uniformly among populations in rural India, perhaps due to effects of the nutrition transition, thus increasing risk of pre- diabetes and diabetes across the population as a whole [36,37]. Thus, future studies examining dietary factors should ensure that the study population is heterogeneous in its dietary intake, and should take into account the shifting nature of diet and nutrition in rural India.

Our study has a number of limitations. Most importantly, the cross-sectional nature of the study precludes the ability to distinguish causes from effects. However, we hope that exclusion of individuals with pre-diagnosed diabetes from the models limited the effects of reverse-causation. Due to limited access to laboratories and transportation constraints, we used CBG instead of venous plasma BG, which has a wider coefficient of variation [19]. However, there is good correlation between CBG and venous plasma estimations [16]. In addition, there has been an increasing emphasis on the associations between diabetes and stress, including co-morbid depression [62,63]. Unfortunately, due to staffing and time constraints, we were unable to assess emotional stress or depression during the questionnaire, and therefore no measure of stress was included in the analyses. This is a notable exception, as stress may be a modifier or confounder for other putative risk factors such as socioeconomic position, obesity, rurality, and diet. Finally, our study sample comprised a small population of adults living in a rural region of Tamil Nadu. It is not nationally representative, and thus findings are not generalizable to the entire population of India.

Research and public health implications of the present study are considerable. Despite 70% of India's population living in rural areas, this portion of the population has largely been ignored by diabetes researchers, who focus their efforts on urban regions where research is logistically easier and prevalence is higher. Our study contributes to the growing body of research suggesting that diabetes is rapidly growing in rural areas and must be addressed. In addition, we have identified a number of potential risk factors, including physical activity, family history, central obesity, abdominal obesity, rurality, polyunsaturated fat consumption, and tobacco consumption, which are all associated with diabetes indicators, pre-diabetes, and/or diabetes in the research site and warrant future investigation. Research such as this should be used to inform allocation of public health resources and education programs to reduce diabetes burdens in rural regions of India.

REFERENCES

[1] International Diabetes Federation. IDF Diabetes Atlas, 6th ed. 2014. http://www.idf.org/sites/default/files/EN_6E_Atlas_Full_0.pdf. Accessed 23 May 2015.

[2] Hwang CK, Han PV, Zabetian A, Ali MK, Venkat Narayan KM. Rural diabetes prevalence quintuples over twenty-five years in low- and middle-income countries: A systematic review and meta-analysis. Diabetes Res Clin Pract. 2012;96(3):271-285.

[3] Misra P, Upadhyay RP, Misra A, Anand K. A review of the epidemiology of diabetes in rural India. Diabetes Res Clin Pract. 2011; 92(3):303-311.

[4] Nichols GA, Hillier TA, Brown JB. Progression from newly acquired Impaired Fasting Glucose to Type 2 diabetes mellitus. Diabetes Care. 2007;30:228-233.

[5] Ajay V, Prabhakaran D, Jeemon P, Thankappan K, Mohan V, Ramakrishnan L et al. Prevalence and determinants of diabetes mellitus in the Indian industrial population. Diabetic Med. 2008;25:1187-1194.

[6] World Health Organization. WHO STEPS Surveillance Manual: The WHO STEPwise approach to chronic disease risk factor surveillance. 2005. http://apps.who.int/iris/bitstream/10665/43376/1/9241593830_eng.pdf?ua=1. Accessed 10 Dec 2014.

[7] International Institute for Population Sciences (IIPS). National Family Health Survey (NFHS-2). Mumbai, India: IIPS;2007.

[8] Ebrahim S, Kinra S, Bowen L, Andersen E, Ben-Shlomo Y, Lyngdoh T, Ramakrishnan L et al. The effect of rural-to-urban migration on obesity and diabetes in India: A cross-sectional study. PLoS Medicine. 2007;7(4):e1000268.

[9] Sudha V, Radhika G, Sathya RM, Ganesan A, Mohan V. Reproducibility and validity of an interviewer-administered semi-quantitative questionnaire to assess dietary intake of urban adults in southern India. Int J Food Sci Nutr. 2006;57(7-8):481-93.

[10] Madras Diabetes Research Foundation. EpiNu® version 1.0. Chennai, India; 2007.

[11] World Health Organization. Global Physical Activity Questionnaire (GPAQ) Analysis Guide. 2011. http://www.who.int/chp/steps/resources/GPAQ_Analysis_Guide.pdf. Accessed 10 November 2013.

[12] Humphreys JS. Delimiting 'rural': implications of an agreed 'rurality' index for healthcare planning and resource allocation. Aust J Rural Health. 1998;6(4):212-216.

[13] Weinert C, Boik R. MSU Rurality Index: Development and evaluation. Res Nurs Health. 1995;18:453-464.

[14] Anjana MR, Pradeepa R, Deepa M, Datta M, Sudha V, Unnikrishnan R et al. The Indian

Council of Medical Research-India Diabetes (ICMR-INDIAB) Study: Methodological Details. J Diabetes Sci Technol. 2011;5(4):906-914.

[15] World Health Organization. Definition and diagnosis of diabetes mellitus and intermediate hyperglycemia. 2006. http://www.who.int/diabetes/publications/Definition%20and%20diagnosis%20of%20diabetes_new.pdf. Accessed 29 Nov 2013.

[16] Priya M, Anjana RM, Pradeepa R, Jayashri R, Deepa M, Bhansali A, Mohan V. Comparison of capillary whole blood versus venous plasma glucose estimations in screening for diabetes mellitus in epidemiological studies in developing countries. Diabetes Technology & Therapeutics. 2011;13(5): 586-591.

[17] Bhavadharini B, Mahalakshmi MM, Maheswari K, Kalaiyasari G, Anjana RM, Deepa M et al. Use of capillary blood glucose for screening for gestational diabetes mellitus in resource-constrained settings. Acta Diabetologica. 2015: 1-7.

[18] Rose GA, Blackburn H, Gillum RF, Prineas RJ. Cardiovascular Survey Methods, 2nd ed. WHO Monograph Series No. 56. 1982. Geneva. World Health Organization.

[19] Anjana RM, Pradeepa R, Deepa M, Datta M, Sudha V, Unnikrishnan R et al. Prevalence of diabetes and prediabets (impaired fasting glucose and/or impaired glucose tolerance in urban and rural India: Phase I results of the Indian Council of Medical Research – INdia DIABetes (ICMR-INDIAB) study. Diabetologia. 2011;54:3022-3027.

[20] World Health Organization. The Asia Pacific perspective. Redefining obesity and its treatment. World Health Organization. International Association for the study of Obesity and International Obesity Task Force. Melbourne International Diabetes Institute; 2000.

[21] StataCorp: College Station TX USA 1985-2013

[22] Census of India 2011 database. Government of India, Ministry of Home Affairs, Office of the Registrar General and Census Commissioner. 2011. http://www.censusindia.gov.in/2011census/C-series/C-13.html. Accessed 15 Jan 2015.

[23] Dohoo I, Martin W, Stryhn H. Linear regression. In: Dohoo I, Martin W, Stryhn W, editors. Veterinary Epidemiologic Research, 2nd ed. Charlottetown, PEI: VER Inc; 2009. p. 323-364.

[24] Pires AM, Rodrigues IM. Multiple linear regression with some correlated errors: classical and robust methods. Stat Med. 2007;26:2901-18.

[25] Vijayakumar G, Arun T, Kutty VR. High prevalence of type 2 diabetes mellitus and other metabolic disorders in rural central Kerala. J Assoc Physicians of India. 2009;57:563-567.

[26] Chow C, Cardona M, Raju PK, Iyengar S, Sukumar A, Raju R et al. Cardiovascular disease and risk factors among 345 adults in rural India – the Andhra Pradesh Rural Health Initiative. Int J Cardiol. 2007;116:180-185.

[27] Ramachandran A, Mary S, Yamuna A, Nurugesan N, Snehalatha C. High prevalence of diabetes and cardiovascular risk factors associated with urbanization in India. Diab Care. 2008;31(5): 893-898.

[28] Misra R, Misra A, Kamalamma N, Vikram NK, Gupta S, Sharma S et al. Difference in prevalence of diabetes, obesity, metabolic syndrome, and associated cardiovascular risk factors in a rural area of Tamil Nadu and an urban area of New Delhi. Int J Diabetes Dev Ctries. 2011;31(2):82-90.

[29] Balagopal P, Kamalamma N, Patel TG, Misra R. A community based diabetes prevention and management education program in a rural village in India. Diab Care. 2008;31:1097-104.

[30] Government of India. SRS Statistical Report. 2011. http://www.censusindia.gov.in/vital_statistics/SRS_Reports.html Accessed 20 February 2015.

[31] Ramachandran A, Snehalatha C, Baskar ADS, Mary S, Sathish Kumar CK, Selvam S et al. Temporal changes in prevalence of diabetes and impaired glucose tolerance associated with lifestyle transition occurring in the rural population in India. Diabetologia. 2004;47(5):860-865.

[32] Nichols GA, Hillier TA, Brown JB. Progression from newly acquired Impaired Fasting Glucose to Type2 diabetes mellitus. Diab Care. 2007;30:228–33.

[33] Mohan V. Why are Indians more prone to diabetes? J Assoc Physicians India. 2004;52:468-474.

[34] Shetty P. Nutrition transition in India. Public Health Nutr. 2002;5(1A):175-82. [35] Kumar P, Mruthyunjaya, Dey MM. Long-term changes in Indian food basket and nutrition. Econ Polit Weekly. 2007;42(35):3567–3572.

[36] Radhika G, Sathya RM, Ganesan A, Saroja R, Vijayalakshmi P, Sudha V, Mohan V. Dietary profile of urban adult population in South India in the context of chronic disease epidemiology (CURES-68). Public Health Nutr. 2011;14(4):591-598.

[37] Ajay V, Prahakaran D, Jeemon P, Thankappan K, Mohan V, Ramakrishnan L et al. Prevalence and determinants of diabetes mellitus in the Indian industrial population. Diabet Med. 2008;25:1187-1194.

[38] Agrawal S, Ebrahim S. Prevalence and risk factors for self-reported diabetes among adult men and women in India: Findings from a national cross-sectional survey. Public Health Nutr. 2011;15(6):1065-1077.

[39] Agrawal RP, Singh G, Nayak KC, Kochar DK, Sharma RC, Beniwal R et al. Prevalence of diabetes in camel-milk consuming ‘Raica’ rural community of northwest Rajasthan. Int J Diab Dev Countries. 2004;24:109-114.

[40] Kokiwar PR, Gupta S, Durge PM. Prevalence of diabetes in a rural area of central India. Int J Diab Dev Countries. 2007;27(1):8-10.

[41] Pandey RM, Gupta R, Misra A, Misra P, Singh V, Agrawal A et al. Determinants of urban-rural differences in cardiovascular risk factors in middle-aged women in India: A cross-sectional study. Int J Cardiology. 2013;163:157-162.

[42] Kesaniemi YA, Danforth AE, Jensen MD, Kopelman PG, Lefebvre P, Reeder BA. Dose-response issues concerning physical activity and health: an evidence-based symposium. Med Sci Sport Exec. 2001;33(6 Suppl):S531-S538.

[43] Little M, Humphries S, Patel K, Dewey C. Factors associated with BMI, underweight, overweight, and obesity among adults in a population of rural south India: A cross-sectional study. 2015. BMC Obes; Manuscript submitted for publication (copy on file with author.

[44] DeFronzo RA. Pathogenesis of type 2 diabetes mellitus. Med Clin North Am. 2004;88:787-835.

[45] Mantzoros CS. Obesity and Diabetes Humana Press: Totowa, New Jersey.

[46] Vazquez G, Duval S, Jacobs DR Jr., Silventoinen K. Comparison of body mass index, waist circumference and waist/hip ratio in predicting incident diabetes: A meta- analysis. Epidemiol Rev. 2007;29:115-129.

[47] Cheng CH, Ho CC, Yang CF, Huang YC, Lai CH, Liaw YP. Waist-to-hip ratio is a better anthropometric index than body mass index for predicting the risk of type 2 diabetes in Taiwanese population. Nutr Res. 2010;30(9):585-593.

[48] Kaye S, Folsom A, Sprafka J, Prineas R, Wallace R. Increased incidence of diabetes mellitus in relation to abdominal obesity in older women. J Clin Epidemiol. 1991;44:329- 334.

[49] Huxley R, James WP, Barzi F, Patel JV, Lear SA, Suriyawongpaisal P et al. Obesity

[50] Stevens J, Couper D, Pankow J, Folsom AR, Duncan BB, Nieto FJ, et al. Sensitivity and specificity of anthropometrics for the prediction of diabetes in a biracial cohort. Obes Res 2001;9:696-705.

[51] Kaur P, Rao SR, Radhakrishnan E, Ramachandran R, Venkatachalam R, Gupte MD. High prevalence of tobacco use, alcohol use, and oberweight in a rural population in Tamil Nadu, India. J Postgrad Med. 2011;57(1):9-15.

[52] Willi C, Bodenmann P, Ghali WA, Faris PD, Cornuz J. Active smoking and the risk of type 2 diabetes: A systematic review and meta-analysis. J Am Med Ass. 2007;298(22):2654-2664.

[53] Will JC, Galuska DA, Ford ES, Mokdad A, Calle EE. Cigarette smoking and diabetes mellitus: evidence of a positive association from a large prospective cohort study. Int J Epidemiol. 2001;30(3):540-546.

[54] Rimm EB, Manson JE, Stampfer MJ, Colditz GA, Willett WC, Rosner B, Hennekens CH et al. Cigarette smoking and the risk of diabetes in women. Am J Public Health.

1993;83(2):211-214.

[55] Persson PG, Carlsson S, Svanstrom L, Ostenson CG, Efendic S, Grill V. Cigarette smoking, oral moist snuff use and glucose intolerance. J Int Med. 2000;248(2):103-110.

[56] Tung TH, Chiu RH, Chen LS, Wu HM, Boucher BJ, Chen THH. A population-based study of the association between areca nut chewing and type 2 diabetes mellitus (Keelung Community-based Integrated Screening programme No. 2). Diabetologia. 2004;47:1776- 1781.

[57] WHO. Report on the global tobacco epidemic. 2013. http://apps.who.int/iris/bitstream/10665/85380/1/9789241505871_eng.pdf?ua=1. Accessed July 29 2015.

[58] Samuel P, Antonisamy B, Raghupathy P, Richard J, Fall CHD. Socio-economic status and cardiovascular risk factors in rural and urban areas of Vellore, Tamilnadu, South India. Int J Epidemiology. 2012;41:1315-1327.

[59] Government of India. Census Terms. 2011. http://censusindia.gov.in/Data_Products/Library/Indian_perceptive_link/Census_Terms_link/censusterms.html. Accessed 31 March 2015.

[61] Hu FB, van Dam RM, Liu S. Diet and risk of type II diabetes: the role of types of fat and carbohydrate. Diabetologia. 2001;44:805-817.

[62] Radhika G, Van Dam RB, Sudha V, Ganesan A, Mohan V. Refined grain consumption and the metabolic syndrome in urban Asian Indians (Chennai Urban Rural Epidemiology Study 57). Metabolism. 2009;58(5):675-681.

[63] Anderson RJ, Freedland KE, Clouse RE, Lustman RJ. The prevalence of comorbid depression in adults with diabetes: A meta-analysis. Diabetes Care. 2001;24(6):1069-78.

[64] Roy T, Lloyd CE. Epidemiology of depression and diabetes: A systematic review. J Affect Disord. 2012;142(Suppl):S8-S21.

TABLES

Table 4.1: Descriptive, socio-economic, physical activity, and dietary characteristics of a sample of individuals in rural south India by diagnostic category following an oral glucose tolerance test

Characteristic	Normoglycemia (n=591)	Pre-diabetes[a] (n=64)	Newly-diagnosed type 2 diabetes[a] (n=53)	Diagnosed type 2 diabetes[a] (n=41)	p-value for trend[b]
Descriptive characteristics					
Age	46.2±14.8	48.7±14.1	50.5±13.8	54.1±12.1	0.001
Women (%)	55.0	59.4	47.1	53.7	0.61
BMI (kg/m^2)	21.2±4.0	23.1±3.9	24.5±4.6	25.3±4.6	<0.001
Waist to Hip Ratio	0.87±0.077	0.90±0.075	0.93±0.10	0.92±0.06	<0.001
Hypertension (%)	25.6	36.5	49.1	57.5	<0.001
Family History of Diabetes (%)	6.3	15.6	11.3	56.1	<0.001
Rurality Index	0.14±0.94	-0.55±1.06	-0.45±1.07	-0.63±1.02	<0.001
Current tobacco consumer (%)	38.7	42.6	56.6	14.6	0.037
Muslim religion (%)	2.5	4.7	9.4	12.2	0.001
Wealth attributes					
Wealth index	10.8±4.5	11.9±5.19	10.6±5.2	11.6±5.3	0.20
Pucca housing (%)	11.7	21.9	15.1	24.4	0.017
In-house tap water (%)	6.6	9.4	15.1	19.5	0.003
Physical activity habits					
Physical Activity (h/day of moderate physical activity)	4.37±3.66	3.15±3.55	1.88±2.68	2.63±3.62	<0.001
Sedentary time (hours/day)	4.26±2.63	4.98±3.17	5.67±2.98	4.92±2.51	<0.001
Television time (h/day)	1.43±1.26	1.80±1.63	1.52±1.44	1.17±0.95	0.012
Labour occupation (%)	62.6	51.6	55.7	40.5	0.015
Livestock ownership (%)	45.1	29.7	26.4	34.1	0.002
Dietary intake					
Current alcohol consumer (%)	48.2	46.8	52.8	26.8	0.051
Total energy intake (kcal/day)	2423.7±758	2241.5±671	2313.3±618	2124.3±504	0.003
Carbohydrates (g/1000 kcal)	180.1±14.1	179.8±14.0	176.7±16.5	175.8±17.1	0.14
Protein (g/1000 kcal)	25.6±1.9	25.5±1.9	25.7±1.9	26.2±1.7	0.25
Total fat (g/1000 kcal)	19.5±5.4	19.5±4.7	20.4±5.2	20.7±5.2	0.39
Dietary fibre (g/1000 kcal)	31.7±11.9	32.6±11.2	30.5±11.2	31.5±12.3	0.82
Dairy products (g/1000 kcal)	79.7±69.7	71.1±51.8	98.8±68.4	89.1±61.1	0.12
Pulses and legumes (g/1000 kcal)	27.3±11.8	29.1±10.7	26.7±12.2	29.6±10.7	0.41
Meat and poultry (g/1000 kcal)	3.16±3.9	3.17±3.8	3.34±4.6	2.67±3.22	0.86
Fruits and vegetables (g/1000 kcal)	76.2±48.6	86.0±57.2	73.3±42.6	70±32.2	0.23
Refined grains (g/1000 kcal)	159.5±82.3	147.1±76.9	136.7±79.4	142.4±72.6	0.14

[a]Based on World Health Organization diagnostic criteria
[b]P-values are for differences in means and proportions of each characteristic between diagnostic categories using one way analyses of variance and Pearson's chi-squared tests, respectively

Table 4.2: Factors associated with two-hour post-prandial capillary blood glucose during an oral glucose tolerance test in a sample of adults (>19 years) in rural south India

Variable	Coefficient	Robust Standard Error	P-value[+]
Constant	-0.23	0.021	<0.001
Physical activity (h/day moderate activity)	$-2.7*10^{-3}$	$04.8*10^{-4}$	<0.001
Body mass index (standardized to one unit SD)	$5.1*10^{-3}$	$2.2*10^{-3}$	0.022
Waist-to-hip ratio (standardized to one unit SD)	$5.7*10^{-3}$	$2.0*10^{-3}$	0.005
Rurality index	$-9.6*10^{-3}$	$1.3*10^{-3}$	<0.001
Intake of polyunsaturated fats (g/1000 kcal)	$-6.8*10^{-4}$	$2.1*10^{-4}$	0.001

[+] P-values are for coefficients in fully-adjusted multivariable linear regression model

Table 4.3: Factors associated with fasting capillary blood glucose in a sample of adults (>19 years) in rural south India

Variable	Coefficient	Robust Standard Error	P-value[+]
Constant	1.28	0.943	0.176
Physical activity (h/day of moderate activity)	-0.056	0.015	<0.001
Body mass index (standardized to one unit SD)	0.41	0.11	<0.001
Waist-to-hip ratio (standardized to one unit SD)	0.17	0.087	0.046
Tobacco use (Y/N)	0.42	0.16	0.011

Abbreviations: h, hours; SD, standard deviation

[+] P-values are for coefficients in fully-adjusted multivariable linear regression model

Table 4.4: Factors associated with pre-diabetes and type 2 diabetes in a sample of adults (>19 years) in rural south India

Variable	Pre-diabetes (IFG and/or IGT) OR and 95% CI	Type 2 diabetes OR and 95% CI
Physical activity (hours/day of moderate physical activity)	0.96 (0.88, 1.04)	0.81[a] (0.72, 0.91)
Family history of diabetes (Y/N)	3.08[a] (1.21, 6.71)	1.74 (0.65, 4.66)
Body mass index (standardized to one unit SD)	1.28[d] (0.94, 1.75)	1.85[a] (1.33, 2.56)
Waist to hip ratio (standardized to one unit SD)	1.33[c] (0.99, 1.80)	1.62[a] (1.18, 2.56)
Rurality index	0.60[a] (0.48, 0.75)	0.76[b] (0.60, 0.97)
Total polyunsaturated fat intake (g/1000 kcal)	0.92[a] (0.88, 0.97)	0.94[b] (0.90, 0.99)
Tobacco use (Y/N)	1.52[d] (0.85, 2.74)	2.82[a] (1.47, 5.41)

Abbreviations: IFG, impaired fasting glucose; IGT, impaired glucose tolerance
Dependent variable is a multinomial categorical variable with the following levels: 0=normoglycemic; 1=pre-diabetes (impaired fasting glucose and/or impaired glucose tolerance); 2=newly-diagnosed diabetes; odds ratios are relative to normoglycemia in fully-adjusted multivariable models
[a]significant to $p<0.01$, [b]significant to $p<0.05$, [c]tendency to $p<0.1$, [d]tendency to $p<0.2$

CHAPTER FIVE:

DECODING THE TYPE 2 DIABETES EPIDEMIC IN RURAL INDIA[1]

ABSTRACT

Type 2 diabetes mellitus is an escalating public health problem in India and is attributed to genetic susceptibility, dietary shift, and rapid lifestyle changes. Historically a disease of the urban elite, quantitative studies have recently confirmed rising prevalence amongst marginalized populations in rural India. To analyse the role of cultural and socio-political factors in diabetes onset and management, we employed in-depth interviews and focus groups in a rural community of Tamil Nadu, south India. The objectives of the study were to understand sources and extent of health knowledge, diabetes explanatory models, and the impact of illness on individual, social, and familial roles. Several cultural, socioeconomic, and political factors appear to contribute to diabetes in rural regions of India, highlighting the need to address structural inequities and empower individuals to pursue health and wellbeing on their own terms.

5.1 Introduction

Type 2 diabetes mellitus (hereafter diabetes) is rapidly emerging as a major threat to global human health (Zimmet, Alberti, and Shaw 2001). As of 2014, 8.3 percent of the world's adult population suffered from diabetes (International Diabetes Federation 2014), with low-income countries in Latin America, Africa, and Asia bearing the brunt of this burden. India's prevalence of diabetes is 7.8 percent and rising, and prevalence in some regions is upwards of 18 percent (Ramachandran et al. 2008). Further, while typically considered a problem of the

[1] *A version of this article is published as:* Little, M., Humphries, S., Patel, K., & Dewey, C. (2016). Decoding the Type 2 diabetes epidemic in rural India. *Medical Anthropology*, 1-15.

urban affluent, diabetes has become a serious concern among rural populations and is contributing to widening health gaps (Shetty 2002). A review of studies in rural India conducted by Misra and colleagues (2011) found that prevalence increased from 1.9 percent in 1994 to upwards of 12 percent in 2009. In addition, rural prevalence of impaired glucose tolerance (IGT, a form of pre-diabetes) ranges from 5.5 to 7.2 percent (Ramachandran et al. 2004). Such figures are concerning, especially considering 72.2 percent of the Indian population live in rural areas characterized by poverty, isolation, and poor access to health services (Government of India 2011).

Diabetes is a complex disease of multifactorial origin. Epidemiological and biomedical discourse and research on the Indian diabetes epidemic tend to focus on proximate individual-level factors such as lifestyle, diet, and exercise, and overlook the roles of distal social, cultural, and political-economic forces (Mendenhall et al. 2010; Rock 2003). The literature also emphasizes genetic factors as a contributing cause of disease for Indian ethnic groups (Ferreira and Lang 2005; Mohan 2004). The result is 'individualization of risk', such that diabetes is perceived by some epidemiologists as individually or ethnically determined, rather than a result of socio-political environment (Diez-Roux 1998). Ultimately, this may place blame on patients' "out-of-control" behaviour (Broom and Whittaker 2004: 2371) and places responsibility for preventing and managing the disease on individuals, rather than inspiring systemic change that alters the course of the epidemic at the population level. Efforts to prevent further rises in diabetes prevalence therefore require the examination of the social, political, and economic structures in which diabetes emerges and is sustained (*Lancet* 2010).

Qualitative inquiry is often used to generate knowledge about lay perceptions and social experiences, which can offer insight into the micro-level health effects of macro-level politics and economics (Brown et al. 2009) and into cultural beliefs which may play an important role in illness management (Greenhalgh et al. 1998; Mendenhall et al. 2012; Stone et al. 2005). While a growing body of research explores the anthropology of diabetes in urban India (Mendenhall et al. 2012; Weaver and Hadley 2011), very few studies focus on rural diabetes. With this in mind, we sought to determine how a rural population understands and experiences diabetes in an area of northwest Tamil Nadu, India. After describing the research methods, we first identify and explore perceptions and knowledge about diabetes – specifically, perceived factors that result in diabetes onset and act as challenges to illness management. Second, we examine illness narratives and present a summary of participants' illness narratives, which include reactions to diagnosis, perceptions of appropriate diabetes management, and the impact of diabetes on normative societal and individual roles (Williams 2004). Overall, our findings contribute to an understanding of diabetes morbidity and mortality in the rural Indian population.

5.2 Methods

5.2.1 Research Setting and Participants

The study took place in 14 villages across two *panchayats* (townships) in Krishnagiri District, northwest Tamil Nadu, from February - April 2013. After receiving ethics approval from the Research Ethics Board at the University of Guelph, we recruited a convenience sample of individuals with diabetes (n=54). One third of participants were recruited over three days at a local government clinic, with additional participants recruited by approaching community leaders and requesting contact with individuals with diabetes who lived locally. We screened all potential participants for eligibility before asking them to participate in the study. We only included those who were over the age of 20, could prove their diabetes status with medical records, and resided in the study region. Response rate was 100 percent. After participants provided informed consent, interviews were scheduled for a later date.

5.2.2 In-depth Interviews

The interview guide was written in English, translated into both Kannada and Tamil, then back-translated to check for accuracy. Interviews were conducted by trained research assistants in the participant's first language, and lasted between 60 and 100 minutes. Each interview began by collecting basic descriptive information, then collected the following: 1) An illness 'free narrative' (Williams 2004); 2) Open-ended questions regarding patient history and experiences with diabetes, as well as perceptions about causes and treatment; 3) A 24-hour dietary recall (Cupples et al. 1992); and 4) Interactive exercises, including construction of a genogram (family health tree) (Greenhalgh et al. 1998) and food picture pile sorting into 'healthy', 'unhealthy', and 'neither healthy nor unhealthy' categories (Tolley, Robinson, and Ulin 2005; Weller and Romney 1988).

5.2.3 Supplementary Methods

We randomly selected 18 individuals from the initial study to participate in a secondary phase of data collection intended to confirm initial findings and gather further information. Methods were as follows:

(1) A structured vignette (10 participants), in which we read participants a standardized story about a fictional character, Rajapandian, who had been diagnosed with diabetes (adapted from Greenhalgh et al. 1998). The story included 24 different statements relating to Rajapandian's beliefs and perceptions about his new disease and treatment seeking. After each of these statements, the participant was asked whether they agreed or disagreed with the story's protagonist, and was encouraged to expand on his or her beliefs.

(2) Two gender-segregated focus groups (four participants each, 8 participants total) were conducted, in which four men and four women separately discussed diabetes and associated topics. Focus groups were conducted in Tamil and facilitated by a trained facilitator. The facilitator used prompts and questions to encourage discussion around issues such as gender and health, stigma, and social constraints (Green and Thorogood 2005).

5.2.4 Data Analysis

Questionnaires were analyzed for basic descriptive characteristics using Microsoft Excel 14.1. Interviews and focus groups were audio-recorded, then translated to English and transcribed within 12 hours. Transcripts were processed separately in NVivo 10 (QSR International 2012) using a thematic content analysis framework developed by Braun and Clarke (2006). First, text was coded using 59 distinct codes. Related codes were amalgamated into themes and each coded passage of text was re-examined for consistency with its overlying theme. Themes were then validated with information from the structured vignette and focus groups and collapsed or expanded if necessary.

5.3 Results and Discussion

Men and women were equally represented in the study. Eleven percent of participants were ≤ 40 years old, 54 percent aged 41-60, and 35 percent ≥ 61 years old. The majority were subsistence farmers and laborers, of whom 66 percent owned land; of these, 78 percent claimed agriculture or livestock was their principal livelihood strategy. 17 percent owned a small shop or local business, and one person was employed in a multi-employee business. All participants were classified as ‘below poverty line’ (BPL) or ‘ultra-poor’ (UP). The population had low formal education; 91 percent of participants including all women had six or fewer years of formal schooling.

5.3.1 General Perceptions of Diabetes

All participants believed that diabetes was a "new" health problem and that prevalence was rising in the study region. One woman told us, "Thirty years ago, nobody had diabetes. We were healthier. Now, it seems that many people are affected, even some young people" (Balagowramma, 69). Understandings of diabetes were rooted in traditional health beliefs, personal experience, and information provided by healthcare providers. Patients viewed doctors as the most important source of knowledge about diabetes. In the structured vignette sessions, most participants (90 percent) agreed with the statement, "Rajapandian thinks that the best way to learn about his diabetes is to speak to doctors." However, doctor-patient interactions are often unproductive and short. One participant told us, "The doctor barely speaks to me. I go in, he checks my blood sugar, my heart[rate] and BP [blood pressure], then writes me a prescription and sends me away" (Nagaraju, 38). According to participants, the mean length of a health check-up with a healthcare provider was three and a half minutes. Focus group participants confirmed that the check-ups were never longer than five minutes.

General awareness of diabetes was low amongst the local population; over two thirds of participants were unaware of diabetes until diagnosis. One participant told us, "I had never heard of the disease before…I didn't have any family with diabetes …the doctor didn't tell me about it until he tested me and diagnosed me" (Puttamma, 56). Short, unproductive doctor-patient interactions and little access to education materials maintained poor biomedical understandings of diabetes, its pathophysiology, and potential complications amongst participants. When we asked, "What happens inside your body when you get sick with diabetes?," 96 percent of participants said, "I don't know". The remaining few stated that diabetes increased their blood sugar, but could not provide further detail. All participants were unaware of the pancreas and its role in insulin secretion and metabolism. While several participants expressed fear of infected lesions and subsequent amputations, none were aware that diabetes could affect their hearts, kidneys, or eyes. Furthermore, participants tended to blame any post-diagnosis health problem on their diabetes, even those likely unrelated, such as cancers and respiratory illnesses. Many participants appeared to lack interest in their disease. Only 44.4 percent said "yes" when asked if they would like to learn more about their condition, and even fewer (41 percent) said they would attend an education session if it were offered for free. As one woman stated, "I don't really care to learn about diabetes. It's no use…the rest of my family has diabetes, so I was always going to get diabetes. There is no use in learning about something when it's inevitable" (Maariyamma, 55).

5.3.2 Explanatory Models

Perceived causes of the diabetes epidemic were varied (Table 5.1). When we asked participants, "What causes diabetes?", the most common response was "poor diet". Often, participants blamed dietary change – specifically, the increasing consumption of "new" or "city" foods like soft drinks, potato chips, sweets, and rice. These products are rapidly the replacing the traditional food basket, comprised mainly of small millets and pulses (Kumar and Dev, 2007). Sugar was implicated in many cases – indeed, the local terms for diabetes were *sacre kaila* in Kannada and *sacre noi* in Tamil, which translate to 'sugar disease'. As one participant stated, "I think [diabetes] is caused by diet. I think that drinking too much tea with sugar will cause it. I used to drink so much tea – maybe 10 cups of tea every day, with lots of sugar. For that reason, I got diabetes" (Vediyappan, 56).

5.3.2.1 Drivers of Dietary Change

Participants identified three primary factors that have catalyzed dietary changes leading to rising prevalence of diabetes. First was the increasing presence and influence of "government shops", the local term for state-mandated fair price shops operated through the Public Distribution System (PDS). Second was as increasing availability of 'new' foods at low prices at local food stalls and shops. And third was a shift in agricultural patterns due to the financial incentives of commercial crop production. We will now explore these three drivers as explained to us by participants.

The PDS is a large-scale food-rationing scheme that provides BPL and UP families in Tamil Nadu with between 20 and 35 kilograms per month of polished white rice, as well as subsidized wheat, sugar, palm oil, pulses, and kerosene (Mooij 1998; Ramakrishnan 2011). Rations are distributed through fair price shops, which are ubiquitous throughout the research site. One woman explained her experiences with the PDS,

> *"The government shop is…about one km away, and is open one day every month. A man comes…and he opens the shop, and we line up, sometimes for hours, to receive our rations. They have big bags of rice, and sugar, oil, kerosene, and sometimes pulses. My family has a BPL card, and I'm supposed to get 20 kilograms of rice for my family, and some of the UP people get more. Some people will bribe the government official and get more than their quota. Even some rich people, they have two or three ration cards, and they come with trucks and take away their quotas to sell them. Sometimes there isn't enough food for us and we get less than our quota, but usually it is fine. But the products are not good quality. Once in a while there are even rocks or insects in the rice! But we still go every month, because we need the food and it is cheap and everyone uses the scheme."* (Channamma, 48)

The PDS has altered the subsistence relationship that farming families have with the food they produce and has catalyzed a shift away from traditional diets. Consider the following, told by a former subsistence farmer and the head of his household:

> *"We grow* ragi *[finger millet],* cholam *[sorghum],* avarai *and* thobarai *[pulses], as well as some vegetables. We also have a tamarind tree that produces fruit. I keep some millet and some pulses, but mostly I sell my food. I get free rice and cheap oil and sugar through the government shop [fair price shop], and I get a good price for my crops. So why wouldn't I sell the food I grow? That way I can have some money. It isn't much money, but what choice do I have?"* (Muniyappan, 52)

This quote suggests that the PDS has fostered an environment in which farmers opt to forego traditional staples in favor of products distributed by the PDS. Detrimental dietary changes in rural regions of India are well studied (e.g. Deaton and Drèze 2009; Deshpande and Rao 2004) yet little published literature has examined the role of the PDS in this trend (Kochar 2005). Nevertheless, participants identified potential connections between PDS and their illness, as one woman explained: "The government rice is not hygienic. It sometimes has rocks in it and it is bad for our bodies…maybe it causes diabetes. But we must eat it, because it is free" (Balagowramma, 69). The potential negative health effects of sugar and polished white rice exist in both biomedical and folk models (Grams et al. 1996; Greenhalgh et al. 1998; Naemiratch and Manderson 2007; Poss and Jezewski 2002). A major oversight of the PDS is that it emphasizes caloric quantity rather than nutritional quality by distributing calorie-dense but nutritionally inferior food products (Deaton and Drèze 2009; Sen 2005). Polished white rice has low fiber content, a high glycemic index, and a poor micronutrient profile (Qi Sun et al. 2010). If consumed in excess, polished rice increases risk of diabetes and reduces glycemic control among individuals with diabetes (Radhika et al. 2009). In addition, the distribution of refined sugar and palm oil encourages increased consumption of these foods. Consequently, despite operating as a social welfare program intended to improve nutritional health, the PDS may indeed be contributing to rising obesity and diabetes.

The PDS is a viable alternative source of staple foods, thus reducing the necessity for subsistence farming and catalyzing a shift towards commercial agriculture, which in turn increases the local dependency on the PDS and purchased food. Participants identified agricultural changes as a second driver of dietary shift. Previously, agriculture in the research site was characterized by diverse cereal and pulses production, however, market liberalization and expansion encouraged farmers to shift from subsistence to commercial production, often reducing crop diversity (Pingali 1997). As one farmer stated, "We used to produce and eat…*samai* [little millet], *varagu* [kodo millet], *arca* [barnyard millet], *cholam* [sorghum], and *thenai* [foxtail millet]. But we stopped growing [these crops] because they were more difficult to grow… we switched to *ragi* [finger millet], which is less work…*ragi* is easy to sell…we keep some but we sell most of it" (Narayanappa, 70). Other farmers had shifted their entire production system to cash cropping and grew tomatoes, groundnuts, bananas, coconuts, or other products with market value. In some cases, farmers signed supply contracts with large food outlets (see also Pingali and Khwaja 2004). Hence most participants were partially or fully immersed in the cash economy, with food for household consumption obtained outside the home.

A third driver of dietary change is the availability of commercial processed foods. One participant, who lived in the largest of the sampled villages, told us, "Thirty years ago, there was only one shop in our village. In that shop, they sold tea, *ragi*, rice, pulses, some root vegetables, and some supplies. But now, there are many shops, and they sell new foods, like sodas, crisps, and sweets. There is even a bakery! They have cakes, pastries, and northern [i.e. north Indian] sweets like *gulab*" (Lakshmi, 64). These comments provide evidence that the study region is experiencing similar trends to those seen at the state level, which include increased availability and intake of sugar sweetened beverages, oily snacks, and sugar (Government of India 2012; Praduman Kumar and Dev 2007; Shetty 2002). Increased availability of processed foods is rooted in recent historical political and economic processes, including market liberalization through structural adjustment programs (see World Bank 2012), which lowered restrictions on food imports and encouraged expansion of processed food distribution into rural regions (Government of India 2014; Vepa 2004; World Bank 2012). Often, participants implicated 'new' foods in explanatory models of diabetes. Participants also claimed that taste preferences of young people are shifting to favor high-fat and high-sugar foods, which Kessler (2007: 44) calls "hyperpalatable" (Pingali and Khwaja 2004). One woman told us, "My children refuse to eat ragi. They only want rice dishes and sweets. All the young people are like this" (Chinnthayi, 46).

5.3.2.2 The Role of 'Tension'

Some 35 percent of participants implicated 'tension' in onset of diabetes and as an ongoing challenge to diabetes management. 'Tension' is an expression adopted from English into many Indian languages, including Kannada and Tamil, and encompasses feelings of stress, grief, depression, and anxiety (Halliburton 2005; Mendenhall et al. 2012; Pereira et al. 2007). Most participants related a personal story about a stressful event that led to diabetes onset. For example, one woman told us, "My son died in a motorcycle accident. From this I had a lot of tension; I cried for two months, I didn't work, my husband got frustrated with me and was very angry. Only a year after, the doctor told me I had diabetes. I think the family troubles caused the diabetes to emerge" (Rajamma, 65). Hunt and colleagues (1998: 961) refer to disease-inducing traumatic events as "provoking factors," and note that immigrant patients in the US perceived diabetes as an inherent characteristic of everyone, but that provoking factors caused the illness to 'come out'. Likewise, several participants viewed diabetes as a latent illness that was 'exposed' by sudden tension, often related to modernization (e.g. vehicle travel, migration of children for work or school) or more traditional stressors (e.g. poverty and low social status) (Mendenhall et al. 2012). Familial stressors such as intergenerational conflicts were also common, as one woman explained: "My sons are working in Bangalore, and I'm worried about them. There is nobody here to work on our land, and I'm getting older. I don't know how I'll care for my remaining children as I get older, so it has caused me tension in the past few years. I think that this tension caused my diabetes" (Prabarvathy, 65).

Tension was not only a perceived cause of diabetes, but also a common outcome or symptom, which corresponds with a growing body of research showing that co-morbid depression is a serious public health issue in India and around the world (Ali et al. 2006; Mendenhall et al. 2012). Tension impeded participants' ability to manage their disease (Schoenberg et al. 2005). Several participants described how stress compromised their capacity to practice optimal self-care. Fear of injury and infection reduced participants' willingness to travel to healthcare facilities or participate in physical activity, which is counter-productive to treatment goals. One man told us, "Diabetes controls my life now. I want to work on the land, but diabetes makes me faint and fall down. I want to do things, but I'm scared of getting a small cut that become[s] infected. I get shaking, like fits [seizures], and a lack of strength. I can barely work. It gives me tension… there are a lot of things that I would like to do but cannot" (Nagaraju, 38).

5.3.2.3 'Tradition'

Ten participants (18.5%) implicated 'tradition' in diabetes onset, a term that is used locally to imply family history. Many participants directly witnessed tradition, as they identified family members with diabetes in their genograms and believed this increased their risk of developing the disease apart from diet and lifestyle factors. One woman summarized her views by stating, "There is no use trying to prevent diabetes. My father had diabetes, my uncle had diabetes, and my brother had diabetes. I was always going to get it. I am telling my oldest son to get tested, because he is getting up every night to pee, and maybe he has it, too" (Rajamma, 65). Another participant told us, "…my mother and father both have diabetes, so I got diabetes. It didn't matter what I ate or what I did, diabetes was always in my blood." (Nagaraju, 38). The concept of heredity as "shared blood" has been previously documented amongst south Asian populations (Greenhalgh et al. 1998: 980), although it is unclear whether such perceptions originate from traditional belief systems or have been introduced by biomedical experts promoting ideas of genetic predisposition.

5.3.3 The Impact of Diabetes

5.3.3.1 Reactions to Diagnosis

When asked, "What were your initial thoughts when you were diagnosed with diabetes?", most participants responded 'tension' or 'fear'. Fear of deterioration and death were common. Many believed that diabetes was imminently fatal and equated diagnosis with a 'death sentence' - "When I was first diagnosed, I was worried about my health. I was scared that I was going to die, that the diabetes would kill me soon. It hasn't killed me yet, but it does get worse year by year" (Geetha, 49). Participants also feared for their ability to maintain a livelihood and support a family while their health deteriorated. Participants lacked social and economic safety nets, so illness was often associated with money problems. As one man explained: “I’m the only one [in my family] who makes any income, and we don’t have any lands or cattle to sell in case of an emergency, so I know if I get sick or die, my family will have money problems” (Raju, 39).

Diabetes was viewed as a life altering, debilitating diagnosis. Actual symptoms, as well as fear of worsening symptoms, affected participants’ lives in a variety of ways. Many had witnessed (in others) or experienced (themselves) fainting, infections, amputations, and death as a result of diabetes. Such experiences increased tension and inhibited individuals from working, travelling, and taking on normative community and familial responsibilities. Several women expressed a fear of pregnancy, as explained below. Eleven (21%) participants were mostly bedridden and could not work.

5.3.3.2 Managing Diabetes

Most participants (91 percent) had taken steps to manage their diabetes, either through diet, medication, insulin, or a combination of these methods (Table 5.2). Two-thirds insisted that pharmaceutical medication (tablets or insulin, locally called ‘Anglo-medicine’) was the most effective way to treat diabetes. However, participants often reported sporadic use of medication, for various reasons. Some believed that medication should only be used to treat bothersome symptoms and ceased pharmaceutical regimens when their diabetes wasn’t “acting up”. One man admitted, “I took medicine until about 20 days ago. I haven’t been bothered by symptoms in three months, so I decided to stop taking medicines. I think the diabetes is controlled” (Raju, 39). Others did not perceive diabetes as a chronic illness, but “bouts” of the same illness, intermittent with periods of being “cured”, and thus justified only occasional use of medicines. One woman told us, “My uncle was cured [of diabetes] for a long time by an ayurvedic doctor in [town 40 km away]. When I feel the diabetes causing problems, I go there to get treated. The doctor gives me tablets and dried plants to take, and tells me that I might be cured if I follow his instructions." (Rajamma, 65). Many also perceived the high cost of medicine as a barrier to treatment. The average monthly expenditure for diabetes treatment was 569.30 rupees (~US $9.29). Due to the subsistence livelihoods of most participants, we were unable to ascertain accurate monthly income values and thus cannot express treatment expenses as a percentage of earnings. However, most participants viewed treatment as prohibitively expensive. Many individuals sought loans or employed emergency measures (e.g. selling cattle or land) to cover their healthcare costs, especially when unforeseen complications arise, as Krishnan (44) related: "I had a very bad infection in my toe from working in my land. I was hospitalized for one month in Bangalore so they could amputate the toe. I spent 500 000 rupees (US ~$8163.82) for the treatment. I couldn't pay so I had to sell 3.5 acres of my 4 acres of land." Very few participants trusted alternative medicines for managing their diabetes, and only three participants used natural or *ayurvedic* medicines and found them effective. Most participants considered such practices to be obsolete and futile. Since diabetes was a 'modern' phenomenon, they suggested, it must be treated with 'modern' medication.

Diabetes management through diet was recognized as important. Two thirds exercised dietary control, largely by avoiding sweet items and reducing their intake of refined carbohydrates such as rice and wheat products, as recommended by their doctors. Many participants, however, stated that they "should be doing more" to control food consumption, citing difficulties related to food access and palatability, and a desire to "eat what everyone else in the family was eating". During the pile-sorting exercises, most participants acknowledged the health benefits of vegetables; although 24-hour dietary recall data suggest that the consumption of these items was low, averaging less than one serving per day. In addition, very few participants avoided high-fat items. Oil (usually groundnut oil or palm oil) was readily consumed by patients and was identified as ‘healthy’ by over two-thirds of participants during the sorting exercise.

While most participants (85 percent) admitted that their doctor had recommended physical activity, only two exercised apart from their normal work duties. Participants reported difficulty incorporating physical activity into their normal routines for various reasons. Most commonly, participants regarded themselves as very busy and cited a lack of free time. One woman told us, “I wake up early, make food for my children, go to work all day, come home, make dinner, and take care of my children. Where is the time to exercise? I must fulfill my responsibilities…I do labor work all day, I cook for my family, I am tired, and then the doctor says ‘you need to walk an hour a day’!” (Saroja, 38). This quote also suggests that exercise is perceived to detract from work and family duties, and may be considered selfish or irresponsible. Other participants, particularly elderly participants, viewed themselves as incapacitated by diabetes or other health problems and therefore unable to exercise. Some recognized this as a negative cycle: “The doctor says I must exercise to feel better, but I have pain in my feet, so I can’t exercise, and so the diabetes gets worse. It’s no use” (Narayanappa, 70). During the focus groups, it became apparent that exercise for health or leisure had little cultural importance or acceptance, and was often met with fears of appearing ‘abnormal’. One man, who worked a sedentary job at a bank, stated, “I don’t have time for exercise. I need to relax in the evenings because my job is stressful. If I just go out and walk around, my friends might say, ‘what is he doing, walking in circles? Has he gone mad?’” (Pachiyappan, 42).

5.3.3.3 Stigma

Several participants identified potential sources of stigma (see also Bajaj et al. 2013; Gopichandran et al. 2012). Many expressed a pre-diagnosis belief that diabetes was infectious, or explained that non-diabetic acquaintances misperceive diabetes as infectious. As one woman explained, when she was initially diagnosed, "I thought, 'oh, we [my family] are going to die' so that's why I was afraid. Because I'd never heard of the disease before and I thought it was very serious and that my whole family would get it" (Puttamma, 56). Another man explained his experiences with social exclusion due to his diabetes, "I used to be the village Chairperson [local leader that represents the village at the district level], but when I was diagnosed with diabetes, I couldn't continue working. Now nobody comes to see me, they avoid me…because they don't want diabetes. Even my family can stay away sometimes" (Chinu, 60). Another source of stigma relates to the notion that women with diabetes are at increased risk of developing complications during pregnancy, and therefore are less desirable spouses (Bajaj et al. 2013). Several women withheld their diagnosis from spouses (or potential spouses), and expressed a post-diagnosis fear of pregnancy. As one woman explained, "I was diagnosed with diabetes young – maybe around age 25. I had two daughters then, but wanted a son. The doctor told me I might have difficulty with pregnancy…but I didn't want to disappoint my husband, so I didn't tell him about the diabetes…I didn't tell anyone. He [my husband] didn't know about it for more than 8 years" (Geetha, 49). These stigmas serve as a further source of tension and exacerbate the difficulties of living with diabetes.

5.3.3.4 *Control, Autonomy, and Empowerment*

Many participants felt that diabetes infringed upon their sense of autonomy by forcing them to become subservient to doctors, caretakers, and family members. Diagnosis was felt to reverse the authoritative relationship an individual had with his or her own health – from *being* *in control* of one's wellbeing to *being controlled* by disease, resulting in a sense of lost autonomy and empowerment (Clark and Anderson 1980; Naemiratch and Manderson 2006). To mitigate this loss, patients attempted to regain some control by perceiving themselves as unique from the 'typical' diseased individual, and therefore abided by a 'different' set of rules that was personally relevant (Ferzacca 2000). This perception, and subsequent actions, manifested in a number of different ways. First, participants were unwilling to accept culpability for their illness, and therefore appeared to feel little personal guilt. When asked, "What causes diabetes?" (general causes) and "What caused *your* diabetes?" (personal causes), answers were often different. While diet was implicated by over 44 percent of participants as a general cause of diabetes, only 13 percent blamed diet for their own illness. Similarly, "lack of exercise" and "tension" were less commonly cited as personal causes. Indeed, when asked about the cause of *their own* diabetes, most participants claimed that they didn't know. One participant elucidated his views by telling us, "I know that diabetes is caused by poor diet, eating too many sweets, drinking too much tea, whatever…But I only eat *ragi* and rice, and maybe a little tea... every day. I'm poor, I don't have enough food. I don't know why I got diabetes" (Raju, 39) Many participants displayed similar attitudes that diabetes was something that "just happened" to them, thus alleviating personal responsibility and perhaps removing themselves from having participated in the poor behavior implicit in general causal models (see also Broom and Whittaker 2004). As a result, diabetes onset was often presented as beyond the control of the participant, and in many cases, inevitable. Removal of guilt may be an attempt by participants to reduce their burden of tension.

Another way in which patients exert autonomy is during treatment. Patients may challenge their subservient role in the doctor/patient relationship by refusing to obey doctors' orders and instead creating a treatment regimen that is personally relevant and therefore empowering (Ferzacca 2000). For example, against doctors' recommendations, participants rarely exercised since physical activity has little personal and cultural value. In addition, as elucidated above, patients often refrained from their prescribed pharmaceutical regimens if and when they felt their diabetes wasn't "acting up". While this behavior may be rooted in necessity (e.g. lack of mobility, financial woes) and is viewed as noncompliant behavior by clinicians, some patients explained their actions as an attempt to regain control. One man told us, "I think many of us [farmers] are stubborn. We disagree with the doctor, maybe not in words, but in actions. He says 'do this, do that', and when I go to the hospital, I tell him, 'yes sir, I'm avoiding sugar. Yes sir, I'm taking tablets. I'm exercising'. But I don't want him to control my life. I think the best way to treat an illness is to just live like it isn't there." (Ramu, 49). Patients may therefore use noncompliance to assert control over their disease and thus recuperate some autonomy lost through diagnosis.

5.4 Limitations and Conclusion

While type 2 diabetes in India has been explored in many epidemiology and clinical studies, comparatively few have studied the anthropology of diabetes in India, and none have focused on rural regions. In the study on which this article is based, we used a range of qualitative and semi-quantitative methods to examine the perceptions and experiences of a group that is widely representative of the population in the region, since it included 50 percent women, a wide age range (32-82 years), and participants were recruited in several different contexts. The study does, however, have some limitations. We selected a convenience sample of 54 individuals in a small geographic area, so data may not reflect experiences amongst other populations in India. We did not assess any measure of diabetes control, and thus were unable to correlate perceptions and experiences with how well individuals were managing their illness. The research team was exclusively male, which may have influenced the emergent narrative during interviews, particularly when discussing sensitive topics such as pregnancy and stigmas. Little research has scrutinized the dynamic resulting from men interviewing women in a social science research context, so it is difficult to determine how gender incongruences may have influenced results (Broom, Hand, and Tovey 2009; Manderson, Bennett, and Andajani-Sutjahjo 2006).

Diabetes is a growing public health concern in India and disadvantaged rural areas are increasingly affected. Although a number of studies draw attention to the prevalence and epidemiology of diabetes in rural regions (see Misra et al. 2011 for a systematic review), none provide qualitative data on perceptions and experiences of people with diabetes. Epidemiology and biomedical literature often blame ethnic predisposition and the ‘nutrition transition’ (characterized by increased sedentarism, urbanization, and consumption of calorie-dense foods) for India’s diabetes epidemic (Mohan 2004; Popkin et al. 2001). Such rhetoric often emphasizes *individual choices and factors* that perpetuate the nutrition transition, such as rural-to-urban migration (Ebrahim et al. 2010), wealth (Corsi and Subramanian 2012), dietary intake (Mohan et al. 2009), and low physical activity (Little et al. 2016; Ramachandran et al. 2001), an approach that overlooks and eclipses the importance of structural social, economic, and political processes in perpetuating the nutrition transition and, subsequently, the diabetes epidemic. Qualitative data are therefore crucial, not only to understand the impact of diabetes on lives and livelihoods, but also to identify perceived structural factors contributing to the diabetes epidemic.

Participants perceived shifting dietary patterns as the primary driver of the diabetes epidemic and identified a number of processes that influenced food intake in recent years. Specifically, participants perceived the increasing presence of the PDS, which subsidizes rice, sugar, and cooking oil, as having an impact on the consumption of the products it provides. In addition, participants acknowledged the role of commercialization of agriculture in reducing the local availability of healthy traditional staples and creating a dependency on foods obtained outside the household. Finally, improved access to 'new' packaged and/or processed foods (such as sodas, candies, baked goods, etc.) due to the expansion of the food processing sector and aggressive rural marketing, has increased consumption of high-fat and high-sugar foods. Therefore, if policymakers wish to combat the nutrition transition and the diabetes epidemic in rural regions of India, it would be prudent to examine these three political and economic drivers and identify opportunities to promote foods with higher fibre content and lower glycemic indices, while simultaneously reducing availability and consumption of 'hyperpalatable' foods. Promoting healthy traditional foods (e.g. millets and pulses) within these processes would be beneficial.

A common theme underlying perceived causes of diabetes and barriers to illness management was poverty. Participants often cited "tension" as a cause of diabetes, and "financial problems" were a common source of tension. Many other tensions were indirectly associated with poverty, such as infant mortality, injuries and infectious illness, and "family problems" induced by financial deficits, migrant labor, or other socioeconomic difficulties. Poverty was also considered a serious barrier to proper diabetes management due to the high costs associated with regular health check-ups, medication, and dietary control. Finally, diabetes management often served to exacerbate poverty, as many participants were required to sell possessions or seek loans to pay for medical treatment of diabetes or associated complications. Thus, while diabetes is often considered a "disease of the affluent" (Mendenhall et al. 2012) in low-income countries, it is increasingly impacting the rural poor (Anjana et al. 2011), and serves to exacerbate the financial difficulties of already-marginalized populations.

While large-scale changes in political and socioeconomic processes may be required to alleviate the risks factors of diabetes in rural regions of India, culturally-sensitive public health education and clinical practices remain important for prevention and proper illness management. Health education that acknowledges patients' illness perceptions is more likely to lead to positive behavior changes (Airhihenbuwa et al. 1995). Given that the participants in this study trusted health professionals as their primary source of health information, clinical check-ups offer an opportunity to share appropriate information and advice with patients. The current study is therefore important for elucidating relevant cultural 'constructs' that can be used to develop public health programming and doctor-patient relationships that concord with patients' beliefs. These constructs include: 'tradition' as an explanatory model; the lack of cultural acceptability of physical activity outside of work duties; stigmas associated with diabetes; perceived loss of autonomy upon diagnosis; ready acceptance of pharmaceutical regimens; and perceived redundancy of medication when diabetes is 'controlled'. The importance of tension among participants suggests that health professionals may need to address the mental health dimensions of diabetes, both prior to and following diagnosis (Mendenhall et al. 2012).

Over the course of this article, we have elucidated socioeconomic and political structures that contribute to diabetes onset and act as barriers to management. We have also identified a number of cultural factors that are relevant to future efforts to halt rising diabetes prevalence and improve the capacity of individuals with diabetes to properly manage their illness. Future research and action must continue to emphasize reducing structural inequities and empowering individuals to improve their quality of life by addressing social, physical, and mental aspects of health.

REFERENCES

Airhihenbuwa, C. O.
1990 A conceptual model for culturally appropriate health education programs in developing countries. International Quarterly of Community Health Education. 11(1):53-62.

Ali, S., M. A. Stone, J. L. Peters, M. J. Davies, and K. Khunti
2006 The prevalence of co-morbid depression in adults with type 2 diabetes: A systematic review and meta-analysis. Diabetic Medicine 23(11): 1165-1173.

Anjana R. M., Pradeepa, R., Deepa, M., Datta, M., Sudha, V., Unnikrishnan, R., Bhansali, A. et al.
2011 Prevalence of diabetes and prediabetes (impaired fasting glucose and/or impaired glucose tolerance in urban and rural India: Phase I results of the Indian Council of Medical Research – India DIABetes (ICMR-INDIAB) study. Diabetologia 54(12):3022-3027.

Bajaj, S., Jawad, F., Islam, N., Mahtab, H., Bhattarai, J., Shrestha, D., Wijeyaratne, C., et al.
2013 South Asian women with diabetes: Psychosocial challenges and management: Consensus statement. Endocrinology and Gender 17(4):548-562.

Braun, V. and V. Clarke
2006 Using thematic analysis in psychology. Qualitative Research in Psychology 3:77-101.

Broom, A., Hand, K., and P. Tovey.
2009 The role of gender, environment, and individual biography in shaping qualitative interview data. International Journal of Social Research Methodology 12(1):51-65.

Broom, D. and A. Whittaker
2004 Controlling diabetes, controlling diabetics: Moral language and the management of diabetes type 2. Social Science & Medicine 58(11):2371-82.

Brown, R. A., J. Kuzara, W. E. Copland, E. J. Costello, A. Angold, A, and C. M. Worthman
2009 Moving from ethnography to epidemiology: Lessons learned in Appalachia. Annals of Human Biology 36:248-260.

Clark, M. and B. G. Anderson
1980 Culture and aging: An anthropological study of older Americans. New York: Arno Press.

Corsi, D.J. and S.V. Subramanian
2012 Association between socioeconomic status and self-reported diabetes in India: A cross-sectional multilevel analysis. BMJ Open 2(4):1-12.

Cupples, J. L., E. S. Cobb, D. R. Miller, and R. B. D'Agostino
1992 Comparison of techniques for estimating nutrient intake: The Framingham Study. Epidemiology 3(2):171-177.

Deaton, A. and J. Drèze
2009 Food and nutrition in India: Facts and interpretations. Economic and Political Weekly 44(7):42-65.

Deshpande, R.S. and V. M. Rao
2004 Coarse cereals in a drought-prone region: A study in Karnataka. Institute for Social and Economic Change. http://www.isec.ac.in/Monograph%202.pdf.

Diez-Roux, A. V.
1998 Bringing context back into epidemiology: Variables and fallacies in multilevel analysis. American Journal of Public Health 88(2):216-222.

Ebrahim, S., Kinra, S., Bowen, L., Anderson, E., Ben-Shlomo, Y., Lyngdoh, T., and L. Ramakrishnan
2010 The effect of rural-to-urban migration on obesity and diabetes in India: A cross-sectional study. PLoS Medicine 7(4):1-12.

Ferreira, M. L., G. C. Lang
2005 Indigenous Peoples and Diabetes: Empowering Community Wellness. Durham, NC: Carolina Academic Press.

Ferzacca, S.
2000 "Actually, I don't feel that bad": Managing diabetes and the clinical encounter. Medical Anthropology Quarterly 14(1):28-50.

Gopichandran, V., Lyndon, S., Angel, M.K., Manayalil, B.P., Blessy, K.R., Alex, R.G., Kumaran, V., Balraj, V.
2012 Diabetes self-care activities: A community-based survey in urban southern India. The National Medical Journal of India 25(1): 14-17.

Government of India
2014 Data on economic parameters of the food processing sector. http://www.mofpi.nic.in

———
2012 Household consumption of goods and services in India. NSS 66th Round, National Statistical Organization http://mospi.nic.in/Mospi_New/site/home.aspx.

———
2011 SRS Statistical Report 2011. http://www.censusindia.gov.in/2011-common/vitalstatistics.html

Grams, G., C. Herbert, C. Heffernan, M.A. Calam B. Wilson, and S. Grzybowski
1996 Haida perspectives on living with non-insulin-dependent diabetes. Journal of The Canadian Medical Association 155:1563-8.

Green, J. and N. Thorogood
2005 Qualitative Methods for Health Research. Thousand Oaks, CA: Sage.

Greenhalgh, T., C. Helman, A. Chodhury
1998 Health beliefs and folk models of diabetes in British Bangladeshis. British Medical Journal 316(7136):978-983.

Halliburton, M.
2005 "Just some spirits": The erosion of spirit possession and the rise of "tension" in South India. Medical Anthropology: Cross-Cultural Studies in Health and Illness 24(2):111-144.

Hunt, L., M. A. Valenzuela, and J. A. Pugh
1998 Porque me tocó a mi? Mexican American diabetes patients' causal stories and their relationship to treatment behaviors. Social Science & Medicine 46:959-969.

International Diabetes Federation
2014 IDF Diabetes Atlas. https://www.idf.org/sites/default/files/Atlas-poster-2014_EN.pdf

Kessler, D. A.
2010 The end of overeating: Taking control of the insatiable American appetite. New York: Rodale Books.

Kochar, A.
2005 Can targeted food programs improve nutrition? An empirical analysis of India's Public Distribution System. Economic Development and Cultural Change 54(1):203-235.

Lancet.
2010 Type 2 diabetes: Time to change our approach. Lancet 375:2193–95.

Little, M., Humphries, S., Patel, K., Dodd, W., and C. Dewey.
2016 Factors associated with glucose tolerance, pre-diabetes, and type 2 diabetes in a rural community of south India: A cross-sectional study. Diabetology and Metabolic Syndrome 8(21).

Mendenhall, E., R. S. Seligman, A. Fernandez, and E. A. Jacobs
2010 Speaking through diabetes: Rethinking the significance of lay discourses on diabetes. Medical Anthropology Quarterly 24(2):220-239.

Mendenhall, E., R. Shivashankar, N. Tandon, M. K. Ali, K. M. Venkat Narayan, and D. Prabhakaran

2012 Stress and diabetes in socioeconomic context: A qualitative study of urban Indians. Social Science & Medicine 75:2522-2529.

Misra, P., R. P. Upadhyay, A. Misra, and K. Anand

2011 A review of the epidemiology of diabetes in rural India. Diabetes Research and Clinical Practice 92:303-311.

Mohan, V.

2004 Why are Indians more prone to diabetes? Journal of Applied Physicians of India 52: 468-474

Mohan, V., G. Radhika, R. M. Sathya, S. R. Tamil, A. Ganesan, and V. Sudha

2009 Dietary carbohydrates, glycaemic load, food groups and newly detected type2 diabetes among urban Asian Indian population in Chennai, India (Chennai Urban Rural Epidemiology Study 59). British Journal of Nutrition 102:1498–1506.

Manderson, L., Bennett, E., and S. Andajani-Sutjahjo

2006 The social dynamics of the interview: Age, class, and gender. Qualitative Health Research 16(10):1317-1334.

Mooij, J.

1998 The political economy of the Public Distribution System in India. Journal of Peasant Studies 25(2):1-22.

Naemiratch, B. and L. Manderson

2006 Control and adherence: Living with diabetes in Bangkok, Thailand. Social Science & Medicine 63:1147-1157.

Naemiratch, B. and L. Manderson

2007 Lay explanations of type 2 diabetes in Bangkok, Thailand. Anthropology & Medicine 14(1):83-94.

Pereira, B., G. Andrew, S. Pednekar, R. Pai, P. Pelto, and B. Patel

2007 The explanatory models of depression in low income countries: Listening to women in India. Journal of Affective Disorders 102:209-218.

Pingali, P.

1997 From subsistence to commercial production systems: The transformation of Asian agriculture. American Agricultural Economics 79:628-634.

Pingali, P. and Y. Khwaja

2004 Globalisation of Indian diets and the transformation of food supply systems.

Inaugural keynote address, 17th Annual Conference of the Indian Society of Agricultural Marketing. http://www.eldis.org/vfile/upload/1/document /0708/doc15357.pdf

Popkin, B. M., S. Horton, S. Kim, A. Mahal, and J. Shuigao
2001 Trends in diet, nutritional status, and diet-related noncommunicable diseases in China and India: The economic costs of the nutrition transition. Nutrition Reviews 59(12):379-390.

Poss, J. and M. A. Jezewski
2002 Mexican Americans' explanatory models of type 2 diabetes. Western Journal of Nursing Research 24(8):840-858.

Praduman Kumar, M. M. and M. M. Dev
2007 Long-term changes in Indian food basket and nutrition. Economic and Political Weekly 42(35):3567-3572.

Qi Sun, P., D. Spiegelman, R. M. van Dam, M. D. Holmes, V. S. Malik, W. C. Willett, F. B. Hu
2010 White rice, brown rice, and risk of type 2 diabetes in US men and women. Archives of Internal Medicine 170(11):961-969.

Radhika, G., R. M. Van Dam, V. Sudha, A. Ganesan, and V. Mohan
2009 Refined grain consumption and the metabolic syndrome in urban Asian Indians (Chennai Urban Rural Epidemiology Study 57). Metabolism – Clinical and Experimental 58:675-681.

Ramachandran, A., Snehalatha C., Kapur, A., Vijary, V., Mohan, V., Das, A. K., Rao, P. C. et al.
2001 High prevalence of diabetes and impaired glucose tolerance in India: National Urban Diabetes Survey. Diabetologia 44:1094-1101.

Ramachandran, A., C. Snehalatha, A. D. S. Baskar, S. Mary, C. K. Sathish Kumar, and S. Selvam
2004 Temporal changes in prevalence of diabetes and impaired glucose tolerance associated with lifestyle transition occurring in the rural population in India. Diabetologia 47:860–865.

Ramachandran, A., S. Mary, A. Yamuna, N. Murugesan, and C. Snehalatha
2008 High prevalence of diabetes and cardiovascular risk factors associated with urbanization in India. Diabetes Care 31(5):893–898.

Ramakrishnan, R.
2011 Free rice distribution scheme in Tamil Nadu from June 1. The Hindu, May 18. http://www.thehindu.com/news/states/tamil- nadu/article2027215.ece.

Rock, M.
2003 Sweet Blood and Social Suffering: Rethinking Cause–Effect Relationships in Diabetes, Distress and Duress. Medical Anthropology 22(2):131–174.

Schoenberg, N. E., E. M. Drew, E. P. Stoller, and C. S. Kart
2005 Situating stress: Lessons from lay discourses on diabetes. Medical Anthropology Quarterly 19(2):171-193.

Sen, P.
2005 Of calories and things: Reflections on nutritional norms, poverty, and consumption behaviour in India. Economic and Political Weekly 40(43):4611-4618.

Shetty, P. S.
2002 Nutrition Transition in India. Public Health Nutrition 5(1A):175-182.

Stone, M., E. Pound, A. Pahcnoli, A. Farooqi, and K. Khunti
2005 Empowering patients with diabetes: A qualitative primary care study focusing on South Asians in Leicester, UK. Family Practice 22(6):647-652.

Tolley, E. E., E. T. Robinson, and P. R. Ulin
2005 Qualitative Methods in Public Health: A Field Guide For Applied Research. San Francisco, CA: Jossey Bass

Vepa, S. S.
2004 Impact of globalization on the food consumption of urban India. In: Globalization of food systems in developing countries: impact on food security and nutrition. Pp. 215-230. Rome: FAO

Weaver, L. J. and C. Hadley
2011 Social pathways in the comorbidity between type 2 diabetes and mental health: concerns in a pilot study of urban middle- and upper-class Indian women. Ethos 39:211-225.

Weller, S. C. and A. K. Romney
1988 Systematic Data Collection. Newbury Park, CA: Sage Publications, Inc.

Williams, G.
2004 Narratives of health inequality: Interpreting the determinants of health. Paper presented at the Annual Meeting of Sociology, San Francisco, CA.

World Bank
2012 Structural adjustment in India. http://lnweb90.worldbank.org/oed/oeddoclib.nsf/DocUNIDViewForJavaSearch/0586CC45A28A2749852567F5005D8C89.

Zimmet P., K. G. Alberti, J. Shaw.
2001 Global and societal implications of the diabetes epidemic. Nature 13; 414 (6865):782-7.

TABLES

Table 5.1 Causal models of diabetes among a sample (n=54) of rural individuals with diabetes[1]

Cited Cause	No. of participants that implicated factor in general (percent)	No. of participants that implicated factor in their diabetes (percent)
Poor diet	24 (44.4)	9 (12.9)
• "New foods" (e.g. soft drinks, chips)	30 (37)	4 (7.3)
• Sugar	18 (33.3)	5 (9.3)
• Rice	4 (7.4)	2 (3.7)
• Other carbohydrates	2 (3.7)	0 (0)
Tension	19 (35.2)	14 (25.9)
Don't know	15 (27.8)	24 (44.4)
Family history	10 (18.5)	8 (14.8)
Lack of exercise	3 (5.6)	0 (0)
Fate	3 (5.6)	2 (3.7)
Drinking	2 (3.7)	2 (3.7)
Other	3 (5.6)	3 (5.6)

[1]Several patients cited multiple causes of T2D

Table 5.2 Diabetes management preferences of a group of individuals (n=54) from a community of rural south India

Treatment	Men (percent)	Women (percent)
Nothing	1 (4)	1 (4)
***Ayurvedic* treatment only**	1 (4)	2 (7)
Diet only	3 (11)	0 (0)
Pharmaceutical tablets (PT) only	6 (22)	7 (26)
Diet + PT	15 (56)	13 (48)
Diet + PT + Insulin	1 (4)	4 (15)

CHAPTER SIX:

THE DOUBLE BURDEN OF UNDER- AND OVER-NUTRITION IN A RURAL POPULATION IN SOUTHERN INDIA

ABSTRACT

Background and Objectives: The double burden of malnutrition is co-occurrence of under-nutrition (e.g. underweight, stunting, and micronutrient deficiencies) and over nutrition (e.g. obesity, type 2 diabetes, and cardiovascular disease) at the population, household, and/or individual level. The objectives of this study were to determine the extent and determinants of individual-level co-morbid anemia and overweight and co-morbid anemia and diabetes in a population in rural Tamil Nadu, south India.

Methods: We undertook a cross-sectional study of adults (n=753) that assessed socio-demographic factors, physical activity levels, and dietary intake. A variety of health outcome measures were examined, including overweight, obesity, diabetes, and anemia. Multivariable logistic regression analyses were employed to determine associations between putative risk factors and two co-morbid double burden pairings: (1) anemia and overweight, and (2) anemia and diabetes.

Results: Prevalence of co-morbid anemia and overweight was 22.6% among women and 12.0% among men. Prevalence of co-morbid anemia and diabetes was 5.6% among both women and men. The following variables were associated with co-morbid anemia and overweight in multivariable models [odds ratio (95% confidence interval)]: female sex [2.3 (1.4, 3.85)], high caste [3.2 (1.34, 7.49)], wealth index [1.1 (1.00, 1.12)], rurality (0.7 [0.56, 0.85]), tobacco consumption [0.6 (0.32, 0.96)], livestock ownership [0.5 (0.29, 0.89)], and

energy-adjusted meat intake [1.8 (0.61, 0.94)]. The following variables were associated with co-morbid anemia and diabetes in multivariable models: age [1.1 (1.05, 1.11)], rurality [0.8 (0.57, 0.98)], and family history of diabetes [4.9 (1.86, 12.70).

Conclusion: Several areas of interest for policy, practice, and research in determining proximate and distal factors driving the nutritional double burden were identified. Women in rural regions of India may be particularly vulnerable to individual-level double burden of malnutrition.

6.1 Introduction

Low- and middle-income countries (LMICs) around the globe are undergoing a 'nutrition transition', characterized by marked dietary transformation and shifting physical activity patterns (Popkin 1998). In India, the nutrition transition is manifest as a shift of diets toward increased intakes of vegetable oils, refined grains, and processed foods, as well as a reduction in the consumption of legumes and coarse cereals (Shetty 2002). In addition, mechanization of labour and urbanization have driven a decline in physical activity patterns. The result has been an abrupt increase in the prevalence of obesity and associated diseases. Recent data suggest prevalence of obesity is approximately 30-40% in some urban populations and 15-30% in some rural populations (Pradeepa et al. 2015). Consequently, obesity-related cardiometabolic diseases are becoming severe public health problems in India; for example, prevalence of type 2 diabetes is 10-18% in urban and 5-13% in rural populations (Anjana et al. 2011b; Bharati et al. 2011; Mohan et al. 2006), while mortality due to ischemic heart disease and stroke account for 21% of all deaths (Centers for Disease Control 2015).

Despite rapid economic development, some populations in India continue to experience persistent poverty and poor environmental sanitation, contributing to under-nutrition and related deficiencies. India has the highest number of severely undernourished people in the world (190 million), representing 15% of its entire population (Food and Agriculture Organization 2014). Approximately 36% of women and 34% of men (age 15-49) are underweight (International Institute for Population Sciences 2007). Meanwhile, micronutrient deficiencies and associated disorders affect a large portion of the population, particularly in rural underserviced regions, where 70% of Indians reside (Jones et al. 2016). In particular, iron-deficiency anemia is an enormous public health concern in India, affecting 56% of women of childbearing age, and is a widely used marker of under-nutrition (IIPS 2007).

The combined burden of overweight and obesity-related diseases, in addition to under-nutrition and micronutrient deficiencies, is called the "double burden of malnutrition". This double burden is common in LMICs undergoing the nutrition transition, and has been reported in Latin America (Caballero 2005; Duran et al. 2006; Pomeroy et al. 2014), south Asia (Ramachandran 2006), south-east Asia (Khan & Khoi 2008; Doak et al. 2005), Eastern Europe (Doak et al. 2005), and Africa (Zeba et al. 2012). In India, the double burden of malnutrition is not limited to the co-occurrence of under-nutrition and obesity at the national level; in fact, it is increasingly common that markers and complications of both under- and over-nutrition occur within the same region, household, and individual (Jones et al. 2016). Individuals who are obese may be simultaneously undernourished, experiencing micronutrient deficiencies and associated disorders. Indeed, obesity may exacerbate conditions such as anemia through inflammation-mediated sequestration of iron stores and inhibited nutrient absorption (Zimmermann et al. 2008). Similarly, individuals who are underweight may simultaneously experience cardio-metabolic outcomes typically associated with obesity (e.g. high blood pressure and diabetes).

While the double burden of malnutrition has been identified, examined, and discussed at the national and subnational levels (IIPS 2007) and between socio-economic groups (Subramanian et al. 2009), very little research has examined these trends at the localized or individual levels (Jones et al. 2016). This is particularly true in rural regions of India, where poverty and poor access to services are pervasive, but diets, lifestyles, and livelihoods are changing rapidly, creating a unique epidemiological environment that may exacerbate the double burden of malnutrition (Subramanian et al. 2009).

The objectives of this study were twofold. First, we evaluated the extent of the double burden of malnutrition at the individual level in two rural *panchayats* in northwestern Tamil Nadu, India by assessing two co-morbidities: (1) anemia and overweight; and (2) anemia and diabetes. Second, we determined the associations between these co-morbidities and a variety of socio-economic, environmental, dietary, and lifestyle factors. We hypothesized that the double burden of malnutrition is prevalent in this population due to recent changes in lifestyle and food consumption patterns and high rates of poverty and low health literacy (Karthikeyan et al. 2012). Overall, we aim to contribute to nutrition and epidemiology research on the double burden of malnutrition in developing countries.

6.2 Methods

6.2.1 Ethics, consent, and permissions

Prior to the study, we obtained ethics approval for the study from a Canadian university ethics board (ethics certificate number 12MY019). We also sought and were granted permission from the High Commission of India in Ottawa, Canada. Prior to conducting field research, we sought and obtained permission from local authorities, including the *panchayat* council, the *Taluk* police supervisor, district police chief, district medical officer, local hospital staff, and the district Foreign Registration Office. Informed verbal consent was received from all participants prior to their enrollment.

6.2.2 Sampling frame and sample selection

We conducted a cross-sectional study in 17 villages in two rural *panchayats* (townships) in the Krishnagiri District of Tamil Nadu. Recruitment of individuals occurred through a randomized two-stage method, in which we approached a random sample of 8% of households in the sampling frame, then employed WHO's Kish method (WHO 2005) to select a single household member (>19 years of age) for the study. If the selected member refused, we employed the Kish method again to select a second member. Pregnant women were excluded. Follow-up appointments with participants collected data on descriptive information using a semi-quantitative survey, dietary intake using a validated food frequency questionnaire (Sudha et al. 2006), and physical activity habits using the WHO's global physical activity questionnaire (WHO 2011).

6.2.3 Measurement and definitions

For each participant, a doctor or a nurse collected anthropometric measurements and health outcomes. Weight, height, waist circumference, and hip circumference were measured using standardized techniques (Anjana et al. 2011a) and body mass index (BMI, kg/m^2) was calculated for each participant. Participants were categorized into the following BMI classes using the cutoffs for Asian populations (WHO 2010): underweight ($<18.5\ kg/m^2$), normal ($\geq 18.5\ kg/m^2$ and $<23\ kg/m^2$), overweight ($\geq 23\ kg/m^2$), obesity class I ($\geq 25\ kg/m^2$ and $< 30\ kg/m^2$), and obesity class II ($\geq 35\ kg/m^2$). Abdominal obesity was defined as waist circumference ≥90 cm for men ≥80 cm for women (WHO 2000). Adults were classified as stunted if their height was less than two standard deviations below the sex-specific reference

Indian population median, calculated as <150.5 cm for men and <139.1 cm for women (National Nutrition Monitoring Bureau 2006).

Blood pressure (BP) was measured with a portable OMRON BP-760 electronic blood pressure monitor (Omron Healthcare, Hoofddorp, Netherlands). BP was recorded as the average of two readings on the right arm after the participant was in the sitting position for at least five minutes. High blood pressure was defined as mean systolic blood pressure ≥ 140 mm Hg and/or mean diastolic blood pressure ≥ 90 mm Hg and/or treatment with blood pressure medication (Chobanian et al. 2003).

Glucose tolerance was determined using an oral glucose tolerance test (OGTT). After an 8-hr minimum overnight fast, we measured fasting capillary blood glucose (CBG) with a One Touch Ultra glucometer (Johnson & Johnson, Milpitas, CA, USA). Oral glucose (75 g anhydrous) was administered and consumed within 5 minutes. Two hours later, we measured post-load CBG (WHO 2006). Diabetes was defined as individuals with proof of previous diagnosis and/or CBG ≥7 mmol/L (≥126 mg/dl) and/or a 2 hr post prandial CBG value ≥12.2 mmol/L (≥220 mg/dL). Impaired glucose tolerance (IGT) was defined as a fasting CBG <7 mmol/L and a 2-h post glucose CBG ≥8.9 mmol/L (≥160 mg/dL) but <12.2 mmol/L (220 mg/dL) (WHO 2006). Impaired fasting glucose (IFG) was defined as a fasting CBG ≥6.1 mmol/L (≥110 mg/dL) and <7 mmol/L (<126 mg/dL) and a 2 h post-glucose CBG <8.9 mmol/L (<160 mg/dL). Pre-diabetes was defined as the existence of IGT or IFG or co-occurrence of both.

Blood hemoglobin (Hb) concentration was assessed using capillary blood samples and a HemoCue® HB201+ analyzer (Hemocue AB, Angelholm, SE). Mild anemia was defined as blood Hb concentration 110-129 g/L for men and 110-119 g/L for women. Moderate and severe anemia were defined as blood Hb concentration 80-109 g/L and < 80 g/L respectively for both men and women.

Socioeconomic status (SES) was assessed with an asset-based wealth index (hereafter referred to as wealth index) using a subset of 13 of 29 questions taken from the Standard of Living Index developed by the International Institute of Population Sciences (IIPS) for use in their National Family and Health Surveys (NFHS) (Table A1.1, Appendix 1) (IIPS 2000). Questions comprising the subset were selected for relevancy to the study population. Attributes and possessions were weighted for a maximum score of 41 using weights developed by the IIPS, based on *a priori* knowledge of their correlation with other measures of SES (Ebrahim et al. 2010). Caste data were categorized as low caste (comprised of scheduled castes and scheduled tribes), middle caste (comprised of other backward castes and most backward castes), and high caste (Brahmin caste). Binary variables were created for low caste and high caste, with middle caste as the referent. Missing values were input for caste if the individual was not Hindu (n=28). Religion was assessed as a binary variable (Muslim vs. Hindu).

6.2.4 Data analysis

FFQ data were processed with EpiNu® (Madras Diabetes Research Foundation, Chennai, TN, IN), which provided information on caloric consumption (kilocalories per day) and average daily macro- and micronutrient intake (grams per day). Nutrient intake variables were scaled to grams per 1000 kcal to account for differences in energy intake between participants. Physical activity scores were calculated using WHO's GPAQ Analysis Guide, which provided a total measure of Metabolic Equivalent (MET) minutes per week. Values were scaled to hours per day of moderate physical activity. Sedentary time was calculated as hours spent sitting per day and television time was calculated as hours spent watching television per day. Body mass index and waist circumference were standardized to a mean of zero and a standard deviation of one for ease or interpretation and comparability.

We calculated a rurality index (RI) value for each individual, adapted from Weinert & Boik (1995). RI was generated by summing the standardized values of (1) number of households in home village (negative value, assigned full weight) and (2) distance to primary health center (in kilometers, assigned half weight). RI values were further standardized to a mean of zero and a SD of one. A higher RI value therefore represented a combination of a greater degree of isolation and lower population density of household location.

Statistical analyses were completed in STATA Version 13.0 (StataCorp, College Station, TX, USA). We calculated the prevalence of seven measures of over-nutrition (overweight, obese class I, obese class II, pre-diabetes, diabetes, high blood pressure, and abdominal obesity) and five measures of under-nutrition (underweight, mild anemia, moderate anemia, severe anemia, and stunted) and co-occurrence of each measure. Prevalence values were age- and sex-standardized using state-level age and sex data from the 2011 national census (Government of India 2011a). We then elected to examine two double burden pairs (DBP). The first DBP (DBP1) was co-morbid anemia and overweight or obese. The second DBP (DBP2) was co-morbid anemia and type 2 diabetes. We created a four-level variable for each DBP. For DBP1, these categories were: 0=neither anemia nor overweight/obese (referent); 1=anemia only; 2=overweight/obese only; and 3=co-morbid anemia and overweight/obese. For DBP2, these categories were: 0=neither anemia nor diabetes (referent); 1=anemia only; 2=diabetes only; and 3=co-morbid anemia and diabetes. We calculated means and proportions of a variety of demographic, wealth, physical activity, and dietary characteristics for each level. Differences in means and proportions were assessed using one-way analysis of variance

(ANOVA) and Pearson's chi-squared tests, respectively. If these tests yielded a significant test result ($p<0.05$), we employed a Sidak pairwise comparison to determine which categories were different from each other.

Using binary variables and the logit command in STATA, we conducted a backward stepwise model-building process to develop separate logistic regressions, using the categories of each DBP as dependent variables, and always using category (0) as the referent, the level of interest as the dependent variable, and excluding all other levels. Outcome variables for DBP1 included anemia, overweight, and co-morbid anemia and overweight, whereas outcome variables for DBP2 included anemia, diabetes, and co-morbid anemia and diabetes. We therefore built a total of three models for each DBP using the same method. First, age- and sex-adjusted bivariate models were assessed to determine factors associated with the outcome at a liberal p-value of 0.2 with anemia, overweight, and co-morbid anemia and overweight (for DBP1 model) or anemia, diabetes, and co-morbid anemia and diabetes (for DBP2 model). Identified factors were then included in initial multivariable logistic regression models. We methodically eliminated non-significant variables using a p-value cut-off of 0.05 from each model, assuming no confounding if coefficients of remaining variables changed by less than 20% after removal of variable. Quadratic terms and interaction terms were assessed if there was biological or practical justification. All models were adjusted for age and sex.

6.3 Results

A total of 812 individuals were recruited for the study. Of these, 753 participated, including 341 men and 412 women. Response rate was 87.4% among men and 99.2% among women. In total, 752 (92.6%) completed a food frequency questionnaire (FFQ) and 749

(92.2%) participated in the oral glucose tolerance test and submitted capillary blood samples for hemoglobin assessment. The mean age of participants was 47 (range 20-92).

Age- and sex-standardized prevalence of underweight, overweight, obesity class I, and obesity class II among the study population were 22.7%, 14.9%, 16.1%, and 3.3% respectively (Little et al. 2016a). Age- and sex-standardized prevalence of IFG, IGT, and type 2 diabetes were 3.9%, 5.6%, and 10.8% respectively (Little et al. 2016b). Of those with type 2 diabetes, 43.6% were previously diagnosed. Age- and sex-standardized prevalence of mild, moderate, and severe anemia were 19.9%, 22.6%, and 4.8% respectively. In total, anemia (mild-severe) affected women (57.2%) almost twice as much as men (35.2%). Many participants had multiple measures of under-nutrition; indeed, 11.8% had both anemia and underweight. Likewise, multiple measures of over-nutrition were common; 6.5% of the population were overweight, had high blood pressure, and also had pre-diabetes or overt diabetes. Only 11.8% (8.0% of women and 16.4% of men) did not have any indication of either under- or over-nutrition (anemia, diabetes, overweight, obesity, abdominal obesity, high blood pressure, stunted, or underweight). These results indicate that a small proportion of the population were adequately nourished and healthy.

Double burden pairings were prevalent in the population (Table 6.1). Overall prevalence of co-morbid anemia and overweight/obesity was 22.6% among women and 12.0% among men. Meanwhile, prevalence of co-morbid anemia and pre-diabetes was 5.3% among women and 2.9% among men, and co-morbid anemia and diabetes was 5.6% among both women and men.

Basic descriptive characteristics of the study population by diagnostic category of DBP1 are displayed in Table 6.2. A significant difference in means or proportions among categories of DBP1 was seen for several attributes, including age, sex, rurality, wealth index, physical activity habits, and dietary intake.

Basic descriptive characteristics of the study population by diagnostic category of DBP2 are displayed in Table 6.3. Again, a significant difference in means or proportions among categories of DBP2 was seen for several attributes, including most age, sex, rurality, family history, religion, wealth index, several measures of physical activity, and dietary intake.

Several factors were associated with co-morbid anemia and overweight in age- and sex-adjusted bivariate logistic regressions at $p<0.05$ (not presented). Following the backward stepwise model-building process, six characteristics (in addition to age and sex) remained significantly associated with co-morbid anemia and overweight (Table 6.4). High caste was associated ($p<0.001$) with increased odds of both overweight and co-morbid anemia and overweight. Wealth index value was associated with increased odds of overweight and co-morbid anemia and overweight, indicating that wealthier individuals were at higher risk of these outcomes. Rurality index value was negatively associated with overweight and co-morbid anemia and overweight, indicating individuals from less rural households experienced a greater risk of having these conditions. Tobacco consumption (current use of *paan* or cigarettes) was negatively associated with co-morbid anemia and overweight. Finally, livestock ownership and meat intake were both negatively associated with co-morbid anemia and overweight.

Several factors were associated with co-morbid anemia and diabetes in age- and sex-adjusted bivariate logistic regressions (not presented). Following the backward stepwise model-building process, three factors (excluding age and sex) remained significantly associated with DBP2 (Table 6.5). High caste was positively associated with co-morbid anemia and diabetes. Greater rurality index value was associated with lower odds of diabetes and co-occurrence of anemia and diabetes. Meanwhile, family history of diabetes was associated with much greater odds of diabetes and co-morbid anemia and diabetes.

6.4 Discussion

Indicators of over- and under-nutrition were widespread, both at the population level and within the same individual, in this subset of adults from two rural *panchayats* in northwestern Tamil Nadu. Prevalence of most measures of under- and over-nutrition in our study population were higher than state-level rural averages and previous regional studies conducted in south India (e.g. Anjana et al. 2011b; NNMB 2006; Oommen et al. 2016). Women were almost twice as likely to suffer from mild, moderate, or severe anemia than men. Prevalence of anemia among the study population (57.3% in women and 35.2% in men) was lower than overall national rural prevalence estimates (75% in women and 55% in men) but higher than state-level rural estimates for Tamil Nadu (49% in women and 29% in men) (NNMB 2006). Underweight was more common among men, which is unusual for an Indian population (e.g. NNMB 2006; Samuel et al. 2012) but prevalence among both men and women (24.7% and 21.0% respectively) were lower than state-level estimates (29.8% in men, 32.5% in women), and also lower than reported by regional studies (e.g. Samuel et al. 2012). Results indicate that rural regions in south India may mirror patterns seen in urban India twenty years ago, inasmuch as the rate of over-nutrition is surpassing that of under-nutrition (Misra et al. 2011a).

The study population had higher prevalence of several measures of over-nutrition in comparison to previous studies in rural India and Tamil Nadu, which may be evidence of continued population-level increases, regional discrepancies, or diagnostic measures (for example, CBG vs. plasma glucose testing) (Priya et al. 2011). This population had one of the highest recorded regional prevalences of diabetes in rural India at 10.8%, and was considerably higher than state-level estimates (7.8% as measured by Anjana et al. 2011b) and most previous regional estimates (see Misra et al. 2011b for review of prevalence studies in rural India), but was similar to a recent cross-sectional study conducted in clusters of villages in nearby Vellore, Tamil Nadu (11.2% as measured by Oommen et al. 2016). Prevalence of overweight (34.3% in men and 38.6% in women) was much higher than state-level rural estimates in 2006 (22.5% in men and 25.1% in women according to NNMB), but similar to other recent regional studies in south India (e.g. Gupta et al. 2010; Kaur et al. 2011). Prevalence of abdominal obesity (25.2% in men and 42.0% in men) was higher than state-level estimates in men (24.6%), but lower than state-level estimates in women (69.1%) (NNMB 2006). More recent estimates, however, suggest a considerable amount of regional variability (Anjana et al. 2011b; Oommen et al. 2016). High blood pressure (31.1% in men and 28.8% in women) was more prevalent than state-level estimates (17.8% among men and 18.4% in women as measured by NNMB 2006) and regional population studies (Oommen et al. 2016; Venkatachalam et al. 2016). Our results corroborate recent evidence suggesting that poor and rural regions are experiencing high rates of obesity, diabetes, hypertension, and other indicators of over-nutrition.

Measures of both under- and over-nutrition were commonly found in the same individual. Few studies in India have reported on the emerging double burden of malnutrition, and even fewer have investigated the co-occurrence of measures of individual-level under- and over-nutrition. Jones and colleagues (2016) found prevalence of co-occurring anemia and overweight as 5.3% in an urbanizing rural region of south India, including 1.3% among men and 9% among women. While Jones and colleagues did not publish prevalence of co-occurring anemia and diabetes, they found overall prevalence of co-occurring anemia and metabolic syndrome (MetS, defined as three of five of abdominal obesity, high triglycerides, low HDL cholesterol, hypertension, or high blood glucose) was 2.8%, including 1.2% among men and 4.5% among women. Our findings suggest that co-morbid anemia and over-nutrition is more common in this study population.

To our knowledge, this is the first cross-sectional study to assess associations between a wide range of demographic, dietary, lifestyle, and environmental risk factors with co-morbid measures of under- and over-nutrition in a rural region of India using multivariable logistic regression models. Several factors were associated with health outcomes, many of which confirm previous research and raise new questions. Our results confirm those of Jones et al. (2016), as well as evidence from other middle-income countries including China (Shi et al. 2008) and Burkina Faso (Zeba et al. 2012) that the co-morbidities of anemia and overweight or of anemia and diabetes affect a larger percentage of women than men. Female sex was also associated with significantly higher odds of co-morbid anemia and overweight in multivariable models. This may be reflective of Indian women being at considerably higher risk of anemia, overweight, and diabetes when compared to men (De Benoist 2008; Gupta et al. 2010; Jones et al. 2016). Such findings raise questions about the potential connections between gender discrimination and the double burden of malnutrition. Recent research conducted by the India Development Survey and Coffey (2017) suggests that “men eat first” in upwards of 50% of households in Uttar Pradesh, which may have severe nutrition implications for women in households with a limited food budget (Coffey 2017; Desai & Vanneman 2012). Furthermore, Coffey indicates that “the person who eats last very often gets less or lower quality food”. While such data are unavailable for households in rural Tamil Nadu, research on children suggests that girls are often neglected in favour of boys, which results in poorer measures of nutrition and excess female mortality (Barcellos et al. 2014; Behrman 1988). Poor maternal and childhood nutrition and may result in cognitive impairment and increased risk of poor measures of health, obesity, and diabetes later in life (Barker 1997). Intra-household dynamics and gender inequality may therefore play a role in women's nutrition, and may exacerbate the double burden of malnutrition among women.

Tobacco use was negatively associated with co-morbid anemia and overweight. This correlation may be explained by the various physiological effects of tobacco, which include appetite suppression (Jo et al. 2002), raising the basal metabolic rate (Perkins et al. 1989) and increased red blood cell formation due to carbon monoxide exposure (Leifert 2008). Ours is the first study to determine that tobacco use may be protective against co-morbid anemia and overweight, however due to the well-known harmful effects of tobacco, including increased risk of cardiovascular disease, type 2 diabetes, and several types of cancer (WHO 2013), tobacco should never form a component of preventive measures against individual-level double burden of malnutrition.

In 2009, Subramanian and colleagues found a "socio-economic segregation" of the burdens of under- and overweight, and stated that "overweight is a disease that primarily afflicts the affluent in India" (Subramanian et al. 2009). Recent studies have shown that low-income populations in urban and rural India are also beginning to experience the effects of the obesity and diabetes epidemic. However, our results show that relative socioeconomic status (SES) remains positively correlated with obesity and diabetes, even in rural populations. In age and sex-adjusted multivariable models, our asset-based wealth index was associated with greater odds of overweight and co-morbid anemia and overweight. In addition, high caste (Brahmin caste) was associated with increased odds of co-morbid anemia and diabetes, while low caste (scheduled caste or tribe status) was associated with decreased odds of co-morbid anemia and overweight. These results indicate that individuals of higher SES and higher caste were more likely to suffer from the effects of simultaneous under- and over-nutrition, perhaps due to dietary and lifestyle patterns associated with wealth and caste (Mohan et al. 2007). While the effects of caste on health and disease are complex, some evidence suggests that high caste populations tend to have lower under-nutrition, higher standards of living, increased income, greater access to sedentary pastimes, and increased usage of vehicles, all of which may impact the risk of obesity and non-communicable diseases (NCDs) (Adinatesh & Prashnar 2013; Dodd et al. 2016). Caste and SES in rural India are intricately linked, and several researchers concur that SES is positively associated with higher risk of obesity and NCDs (Kinra et al. 2010; Zaman et al. 2012). While we would expect that higher caste and SES might reduce risk of anemia and co-morbid anemia (Bentley & Griffiths 2003) due to improved food access, this does not appear to be the case, perhaps due to the tendency of wealthier Indian populations to consume a diet high in calories but low in micronutrients (Aloia et al. 2011; Deaton & Drèze 2009). Such findings correspond to research in China that found higher prevalence of co-morbid anemia and MetS among rich and urban participants (Shi et al. 2008). Jones and colleagues (2016) also found that their household asset index was associated with increased odds of co-occurring anemia and overweight, as well as co-occurring anemia and MetS.

The rise of NCDs in India is often attributed to urbanization. While our study region was primarily agricultural, and was classified as rural by Census India definitions (Government of India 2011b), we employed a rurality index to assess the impacts of isolation and population density on measures of under- and over-nutrition. We found strong negative associations between rurality and risk of obesity, diabetes, co-morbid anemia and obesity, and co-morbid anemia and diabetes. These findings parallel those of Jones et al. (2016), who found that increased urbanicity (based on nighttime light intensity) in a rural region of Tamil Nadu was associated with greater odds of MetS and co-occurrence of anemia and MetS. In addition, sibling-matched and cohort studies on migrants suggest that urbanization is associated with food and physical environments that are conducive to obesity, diabetes, and other cardio-metabolic diseases (Allender et al. 2010; Ebrahim et al. 2010). Shi et al. (2008) also found that rural status was associated with lesser odds of individual-level double burden of malnutrition in China. It is likely that despite the rural locale of our study, certain socioeconomic, lifestyle, and dietary patterns are associated with and represented by the rurality index, contributing to its associations with a number of health outcomes.

There is some evidence to suggest that micronutrient deficiencies may contribute to the development and exacerbation of noncommunicable diseases, and conversely that NCDs may affect absorption of micronutrients, thus exacerbating micronutrient deficiency (Eckhardt et al. 2008). For example, micronutrients such as Vitamin C and zinc have antioxidant effects, and oxidative stress has been linked to the development and prognosis of cardiovascular disease (Lakshmi et al. 2009) and diabetes (Rahimi et al. 2005). Some studies suggest that obesity and some NCDs further exacerbate oxidative stress, and may interact with dietary deficiencies to produce worse health outcomes (Furukawa et al. 2004; Thompson & Godin 1995). Similarly, evidence indicates that inflammation caused by obesity and diabetes reduces iron absorption, which may contribute to iron-deficiency anemia in individuals with these conditions (Aigner, et al. 2014; Zimmermann et al. 2008). Such complex physiological pathways may partially explain why body mass index and waist-hip-ratio were positively associated with co-morbid anemia and diabetes in the study population. In addition, the coexistence of underweight, anemia, and diabetes appears consistent with malnutrition-related diabetes or fibrocalculous pancreatic diabetes (FCPD), for which malnutrition and micronutrient deficiencies may be etiological factors (Mohan & Premalatha 1995). It is possible that some individuals in the study were misdiagnosed with type 2 diabetes and in fact suffered from FCPD, however considering the low prevalence of FCPD in other regions of south India (e.g. 0.019% in urban Chennai and 0.13% in rural Kerala), misclassification in this population was likely nonexistent or negligible (Balaji et al. 1994; Mohan et al. 2008). Clearly, there are several potential links between nutrition intake, micronutrient deficiency and NCDs that need to be explored in further detail, and may explain the high rates co-morbidity in the present study.

Studies from the United States have suggested that a "westernized" diet consisting of energy-dense but micronutrient-poor foods may contribute to concurrent obesity and micronutrient deficiencies (Cordain et al. 2005). India is undergoing a nutrition transition characterized by a decline in the per capita consumption of traditional grains and a diversification of food consumption. In some ways, this shift mirrors changes in many countries in the global north, including increased intake of refined sugars, saturated fats, and animal products (Kumar & Dey 2007; Shetty 2002). Of concern in rural regions is the increasing popularity of refined grains, and in particular polished white rice, which has been processed to eliminate the bran and germ portions, thus removing fibre, vitamins, and other compounds that may protect against micronutrient deficiencies, diabetes, and other NCDs (Mohan et al. 2010). India's nutrition transition is driven by rising incomes, economic development, urbanization, increased access to processed foods, changing food preferences, and shifting agricultural patterns, all of which are influenced by government policy and market forces (Mohan et al. 2007; Shetty 2002).

India's food policy has been instrumental in dietary changes over the past several decades. Under-nutrition in India has been called a "major embarrassment" (Kapil & Sachdev 2010) and a "national shame" (Reddy 2012), and as such, food and health policy has been preoccupied with improving caloric intake to reduce acute malnutrition rather than improving overall nutrition. This has been termed 'caloric fundamentalism' by Headey and colleagues (2011). Caloric fundamentalism underlies government programs like the Public Distribution System (PDS) and the Midday Meal Scheme (MMS), which now fall under India's National Food Security Act of 2013. These programs aim to improve food security by distributing and subsidizing food products. While the PDS and the MMS have seen some success (most notably reducing the incidence of acute malnutrition), they have been criticized for promoting meals high in refined carbohydrates, low in protein, and lacking in adequate nutritional quality to prevent micronutrient deficiencies (Ministry of Human Resource Development 2015). Indeed, one study audited 2102 MMS school programs and found that 89% failed to meet the mandated nutrition standard (Ministry of Human Resource Development 2015). Audits of the PDS have confirmed multiple systemic issues (Gulati & Saini 2015), but have not assessed the nutritional quality of foods. Nevertheless, consequences of both the PDS and MMS may include promoting consumption of refined grain, sugar, and oil over coarse cereals, fruits, and vegetables, with potential effects on risk of micronutrient deficiencies and NCDs. Indeed, some authors have postulated that the PDS and MMS may be exacerbating the burden of overweight and diabetes in rural India (Harriss-White 2004; Khera 2011; Little et al. 2016c; Thow et al. 2016). While in their present forms these programs may be counter-productive, they represent an opportunity to promote nutritional *quality* rather than simply *quantity* of calories, thus simultaneously improving health outcomes related to under- and over-nutrition (Thow et al. 2016).

Despite the well-known impacts of diet on risk of anemia, overweight, and diabetes, very few dietary variables remained significant in the multivariable models in this study. Meat consumption was associated with decreased odds of anemia (in the DBP2 model) and co-morbid anemia and overweight. This is expected, considering the high iron content of meat, and particularly red meat such as mutton, which was common in the research site (Lombardi-Boccia 2002). Similarly, livestock ownership is likely a proxy for meat consumption and physical activity, which may contribute to its association with decreased odds of co-morbid anemia and overweight (Ehui et al. 1998). The lack of significant associations between dietary variables and health outcomes may be indicative of the limitations of the FFQ to adequately capture dietary intake information (Sudha et al. 2006).

In addition to those of the FFQ, this study has several limitations. Although we used systematic random sampling to ensure internal validity, the sample is likely not representative of the state or national rural population, and thus our findings cannot be generalized to other populations in India. We determined associations between several risk factors and health outcomes; however the cross-sectional sampling methods preclude our ability to determine causality. In addition, although we employed validated methods to collect most data, there were some notable exceptions. Our asset-based wealth index was modified from the validated one used by the NFHS, and was not validated against other measures of wealth. Our rurality index was adapted from one developed for health research in the United States, but was not previously validated for use in India (Weinert & Boik, 1995). Finally, due to limited access to laboratories and transportation constraints, we used CBG, which has a wider coefficient of variation than venous plasma BG (Anjana et al. 2011b). However, previous studies have shown good correlation between CBG and venous plasma estimations, and the WHO recommends CBG in resource-poor settings (Priya et al. 2011; WHO 2006).

In conclusion, under- and over-nutrition should not be considered distinct conditions at opposite ends of the nutrition spectrum; rather, they may occur simultaneously in populations and within an individual. We found very high prevalence of co-morbid anemia and overweight, as well as co-morbid anemia and diabetes, indicating that the double burden of malnutrition is a severe public health concern in rural regions of southern India. The double burden of malnutrition must be addressed by research, public health messaging, policy, and clinical practice, particularly in the context of a rapid nutrition transition.

REFERENCES

Adinatesh, K. V., Prashanr, R. K. (2013). Prevalence of childhood obesity among school children in Karimnagar town. *MRIMS Journal of Health Science*, *1*(1):8-11.

Aigner, E., Feldman, A., & Datz, C. (2014). Obesity as an emerging risk factor for iron deficiency. *Nutrients*, *6*(9), 3587-3600.

Allender, S., Lacey, B., Webster, P., Rayner, M., Deepa, M., et al. (2010). Level of urbanization and noncommunicable disease risk factors in Tamil Nadu, India. *Bulletin of the World Health Organization*, *88*(4), 297-304.

Aloia, C. R., Gasevic, D., Yusuf, S., Teo, K., Chockalingam, A., et al. (2011). 61-Differences in fast food consumption between individuals of high and low socio-economic status in Chandigarh, India. *Canadian Journal of Diabetes*, *35*(2), 156.

Anjana, R. M., Pradeepa, R., Deepa, M., Datta, M., Sudha, V, et al. (2011). The Indian Council of Medical Research—India Diabetes (ICMR-INDIAB) Study: Methodological Details. *Journal of Diabetes Science and Technology*, *5*(4), 906-914.

Anjana, R. M., Pradeepa, R., Deepa, M., Datta, M., Sudha, V., Unnikrishnan, R., et al. (2011b). Prevalence of diabetes and prediabetes (impaired fasting glucose and/or impaired glucose tolerance) in urban and rural India: Phase I results of the Indian Council of Medical Research–INdia DIABetes (ICMR–INDIAB) study. *Diabetologia*, *54*(12), 3022-3027.

Balaji, L. N., Tandon, R. K., Tandon, B. N., & Banks, P. A. (1994). Prevalence and clinical features of chronic pancreatitis in southern India. *International Journal of Pancreatology*, *15*(1), 29-34.

Barcellos, S. H., Carvalho, L. S., & Lleras-Muney, A. (2014). Child gender and parental investments in India: are boys and girls treated differently? *American Economic Journal: Applied Economics*, *6*(1), 157-189.

Barker, D. (1997). Maternal nutrition, fetal nutrition, and disease later in life. *Nutrition, 13*(9), 807-813.

Behrman, J. R. (1988). Intrahousehold allocation of nutrients in rural India: Are boys favored? Do parents exhibit inequality aversion? *Oxford Economic Papers*, *40*(1), 32-54.

Bentley, M. E., & Griffiths, P. L. (2003). The burden of anemia among women in India. *European Journal of Clinical Nutrition*, *57*(1), 52-60.

Bharati, D. R., Pal, R., Kar, S., Rekha, R., Yamuna, T. V., & Basu, M. (2011). Prevalence and determinants of diabetes mellitus in Puducherry, South India. *Journal of Pharmacy and Bio-allied Sciences*, *3*(4), 513.

Caballero, B. (2005). A nutrition paradox—underweight and obesity in developing countries. *New England Journal of Medicine*, *352*(15), 1514-1516.

Centres for Disease Control. (2015). CDC India Fact Sheet. Available at: https://www.cdc.gov/globalhealth/countries/india/pdf/india.pdf. Accessed 16 Feb 2017.

Chobanian AV, Bakris GL, Black HR, Cushman WC, Green LA, et al. (2003). The seventh report of the Joint National Committee on Prevention, Detection, Evaluation and Treatment of High Blood Pressure (JNC-7). *Journal of the American Medical Association, 289*:2560– 2571.

Coffey, D. (2017). When women eat last. *The Hindu, Jan. 7th 2017 edition.* Available at: http://www.thehindu.com/opinion/op-ed/When-women-eat-last/article16978948.ece?homepage=true. Accessed 16 March 2017.

Cordain, L., Eaton, S. B., Sebastian, A., Mann, N., Lindeberg, S., et al. (2005). Origins and evolution of the Western diet: health implications for the 21st century. *The American Journal of Clinical Nutrition*, *81*(2), 341-354.

Deaton, A., & Drèze, J. (2009). Food and nutrition in India: facts and interpretations. *Economic and Political Weekly*, 42-65.

De Benoist, B., McLean, E., Egli, I., & Cogswell, M. (2008). Worldwide prevalence of anaemia 1993-2005: WHO global database on anaemia. *Geneva: WHO*. Available at: http://apps.who.int/iris/bitstream/10665/43894/1/9789241596657_eng.pdf. Accesse 3 April 2017.

Desai, S., & Vanneman, R. (2012). India Human Development Survey II (IHDS-II). [TSV dataset]. Available at: http://ihds.info/. Acceessed 16 March 2017.

Doak, C. M., Adair, L. S., Bentley, M., Monteiro, C., & Popkin, B. M. (2005). The dual burden household and the nutrition transition paradox. *International Journal of Obesity*, *29*(1), 129-136.

Dodd, W., King, N., Humphries, S., Little, M., & Dewey, C. (2016). Self-reported morbidity and health service utilization in rural Tamil Nadu, India. *Social Science & Medicine*, *161*, 118-125.

Duran, P., Caballero, B., & De Onis, M. (2006). The association between stunting and overweight in Latin American and Caribbean preschool children. *Food and Nutrition Bulletin*, *27*(4), 300-305.

Ebrahim, S., Kinra, S., Bowen, L., Andersen, E., Ben-Shlomo, Y., et al. (2010). The effect of rural-to-urban migration on obesity and diabetes in India: a cross-sectional study. *PLoS Med*, *7*(4), e1000268.

Eckhardt, C. L., Torheim, L. E., Monterrubio, E., Barquera, S., & Ruel, M. T. (2008). The overlap of overweight and anaemia among women in three countries undergoing the nutrition transition. *European Journal of Clinical Nutrition*, *62*(2), 238-246.

Ehui, S., Li-Pun, H., Mares, V., & Shapiro, B. (1998). The role of livestock in food security and environmental protection. *Outlook on Agriculture*, *27*(2), 81-87.

Food and Agricultural Organization. (2014). The state of food insecurity in the world. Available at: http://www.fao.org/publications/sofi/2014/en/. Accessed 19 Feb 2017.

Furukawa, S., Fujita, T., Shimabukuro, M., Iwaki, M., Yamada, Y., et al. (2004). Increased oxidative stress in obesity and its impact on metabolic syndrome. *The Journal of Clinical Investigation*, *114*(12), 1752-1761.

Government of India. (2006). 11th Five-Year Plan: Nutrition and Social Safety Net. Available at: http://planningcommission.gov.in/plans/planrel/fiveyr/11th/11_v2/11v2_ch4.pdf. Accessed 19 Feb 2017.

Government of India. (2011a). SRS Statistical Report. Available at: http://www.censusindia.gov.in/vital_statistics/SRS_Reports.html. Accessed 20 February 2015

Government of India. (2011b). Census Terms. Available at: http://censusindia.gov.in/Data_Products/Library/Indian_perceptive_link/Census_Terms_link/censusterms.html. Accessed 31 March 2015.

Gulati, A. & Saini, S. (2015). Working Paper 294: Leakages from the Public Distribution System and the way forward. Available at: http://icrier.org/pdf/Working_Paper_294.pdf. Accessed 16 February 2017.

Gupta, S. K., Singh, Z., Purty, A. J., Kar, M., Vedapriya, D. R., Mahajan, P., & Cherian, J. (2010). Diabetes prevalence and its risk factors in rural area of Tamil Nadu. *Indian Journal of Community Medicine*, *35*(3), 396.

Harriss-White, B. (2004). Nutrition and its politics in Tamil Nadu. *South Asia Research*, *24*(1), 51-71.

Headey, D., Chiu, A., & Kadiyala, S. (2011). *Agriculture's role in the Indian enigma: Help or hindrance to the undernutrition crisis?* (No. 1085). International Food Policy Research Institute (IFPRI).

International Institute for Population Sciences (IIPS). (2000). National Family Health Survey (NFHS-2). Mumbai, India: IIPS. Available at: http://www.dhsprogram.com/pubs/pdf/FRIND2/FRIND2.pdf. Accessed 16 Feb 2017.

International Institute for Population Sciences (IIPS). (2007). National Family Health Survey (NFHS-3). Mumbai, India: IIPS. Available at: http://rchiips.org/nfhs/NFHS-3%20Data/VOL-1/India_volume_I_corrected_17oct08.pdf. Accessed 16 Feb 2017.

Jo, Y. H., Talmage, D. A., Role, L. W. (2002). Nicotinic receptor-mediated effects on appetite and food intake. *Journal of Neurobiology, 53*(4), 618-632.

Jones, A. D., Hayter, A. K., Baker, C. P., Prabhakaran, P., Gupta, V., et al. (2016). The co-occurrence of anemia and cardiometabolic disease risk demonstrates sex-specific sociodemographic patterning in an urbanizing rural region of southern India. *European Journal of Clinical Nutrition*, *70*(3), 364-372.

Kapil, U., & Sachdev, H. P. (2010). Management of children with severe acute malnutrition: a national priority. *Indian Pediatrics*, *47*(8), 651-653.

Karthikeyan, M., Jena, D., Patel, K., Khadka, K., Devkota, R., Samaratunga, H., & Sakkari, K. (2012). Baseline Survey in Project Sites: A Report as a Part of 'Revalorizing Small Millets in the Rainfed Regions of South Asia (RESMISA)', India, Nepal, Sri Lanka and Canada: DHAN Foundation, Arthacharya Foundation, Local Initiatives for Biodiversity, Research and Development (LIBIRD) and Canadian Mennonite University.

Kaur, P., Rao, S. R., Radhakrishnan, E., Ramachandran, R., Venkatachalam, R., & Gupte, M. D. (2011). High prevalence of tobacco use, alcohol use and overweight in a rural population in Tamil Nadu, India. *Journal of Postgraduate Medicine*, *57*(1), 9-15.

Khan, N. C., & Khoi, H. H. (2008). Double burden of malnutrition: the Vietnamese perspective. *Asia Pacific Journal of Clinical Nutrition*, *17*(S1), 116-118.

Khera, R. (2011). Revival of the public distribution system: evidence and explanations. *Economic and Political Weekly*, *46*(44-45), 36-50.

Kinra, S., Bowen, L.J., Lyngdoh, T., Prabhakaran, D., Reddy, K. S., Ramakrishnan, L. et al. (2010). Sociodemographic patterning of non-communicable disease risk factors in rural India: a cross-sectional study. *British Medical Journal, 341*:c4974

Kumar, P., & Dey, M. M. (2007). Long-term changes in Indian food basket and nutrition. *Economic and Political Weekly*, 3567-3572.

Lakshmi, S. V., Padmaja, G., Kuppusamy, P., & Kutala, V. K. (2009). Oxidative stress in cardiovascular disease. *Indian Journal of Biochemistry & Biophysics, 46*(6), 421-440.

Leifert, J. A. (2008). Anaemia and cigarette smoking. *International Journal of Laboratory Hematology*, *30*(3), 177-184.

Little, M., Humphries, S., Patel, K., Dodd, W., & Dewey, C. (2016a). Factors associated with glucose tolerance, pre-diabetes, and type 2 diabetes in a rural community of south India: a cross-sectional study. *Diabetology & Metabolic Syndrome*, *8*(1), 21-.

Little, M., Humphries, S., Patel, K., & Dewey, C. (2016b). Factors associated with BMI, underweight, overweight, and obesity among adults in a population of rural south India: a cross-sectional study. *BMC Obesity, 3*(1), 12.

Little, M., Humphries, S., Patel, K., & Dewey, C. (2016c). Decoding the Type 2 Diabetes Epidemic in Rural India. *Medical Anthropology*, 1-15.

Lombardi-Boccia, G., Martinez-Dominguez, B., Aguzzi, A. (2002). Total heme and non-heme iron in raw and cooked meats. *Journal of Food Science, 67*, 1738–41.

Ministry of Human Resource Development. (2015). Performance Audit of Mid Day Meal Scheme. Available at: http://www.indiaenvironmentportal.org.in/files/file/performance%20audit%20of%20mid%20day%20meal%20scheme.pdf. Accessed 5 Feb 2017.

Misra, A., Singhal, N., Sivakumar, B., Bhagat, N., Jaiswal, A., & Khurana, L. (2011a). Nutrition transition in India: Secular trends in dietary intake and their relationship to diet-related non-communicable diseases. *Journal of Diabetes*, *3*(4), 278-292.

Misra, P., Upadhyay, R. P., Misra, A., Anand, K. (2011b). A review of the epidemiology of diabetes in rural India. *Diabetes Research and Clinical Practice, 92*(3):303-311.

Mohan, V., & Premalatha, G. (1995). Fibrocalculous pancreatic diabetes. *The International Journal of Diabetes and Metabolism*, *3*, 71-82.

Mohan, V., Deepa, M., Deepa, R., Shanthirani, C. S., Farooq, S., Ganesan, A., & Datta, M. (2006). Secular trends in the prevalence of diabetes and impaired glucose tolerance in urban South India—the Chennai Urban Rural Epidemiology Study (CURES-17). *Diabetologia*, *49*(6), 1175-1178.

Mohan, V., Sandeep, S., Deepa, R., Shah, B., & Varghese, C. (2007). Epidemiology of type 2 diabetes: Indian scenario. *Indian Journal of Medical Research*, *125*(3), 217.

Mohan, V., Farooq, S., & Deepa, M. (2008). Prevalence of fibrocalculous pancreatic diabetes in Chennai in South India. *Journal of Pancreas, 9*(4), 489-492.

Mohan, V., Radhika, G., Vijayalakshmi, P., & Sudha, V. (2010). Can the diabetes/cardiovascular disease epidemic in India be explained, at least in part, by excess refined grain (rice) intake? *The Indian Journal of Medical Research*, *131*, 369-72.

National Nutrition Monitoring Bureau. (2006). Diet and nutritional status of population and prevalence of hypertension among adults in rural areas. Available at: http://nnmbindia.org/nnmbreport06nov20.pdf. Accessed 8 February 2017.

Neel, J. V. (1962). Diabetes mellitus: a "thrifty" genotype rendered detrimental by "progress"? *American Journal of Human Genetics*, *14*(4), 353.

Oommen, A. M., Abraham, V. J., George, K., & Jose, V. J. (2016). Prevalence of risk factors for non-communicable diseases in rural & urban Tamil Nadu. *Indian Journal of Medical Research*, *144*(3), 460.

Perkins, K. A., Epstein, L. H., Stiller, R. L., Marks, B. L., & Jacob, R. G. (1989). Acute effects of nicotine on resting metabolic rate in cigarette smokers. *The American Journal of Clinical Nutrition*, *50*(3), 545-550.

Pomeroy, E., Stock, J. T., Stanojevic, S., Miranda, J. J., Cole, T. J., & Wells, J. C. (2014). Stunting, adiposity, and the individual‐level "dual burden" among urban lowland and rural highland Peruvian children. *American Journal of Human Biology*, *26*(4), 481-490.

Popkin, B. M. (1994). The nutrition transition in low‐income countries: an emerging crisis. *Nutrition Reviews*, *52*(9), 285-298.

Popkin, B. M. (1998). The nutrition transition and its health implications in lower-income countries. *Public Health Nutrition*, *1*(01), 5-21.

Pradeepa, R., Anjana, R. M., Joshi, S. R., Bhansali, A., Deepa, M., et al. (2015). Prevalence of generalized & abdominal obesity in urban & rural India-the ICMR-INDIAB Study (Phase-I)[ICMR-INDIAB-3]. *Indian Journal of Medical Research*, *142*(2), 139.

Priya, M., Anjana, R. M., Pradeepa, R., Jayashri, R., Deepa, M., Bhansali, A., & Mohan, V. (2011). Comparison of capillary whole blood versus venous plasma glucose estimations in screening for diabetes mellitus in epidemiological studies in developing countries. *Diabetes Technology & Therapeutics. 13*(5), 586-591.

Rahimi, R., Nikfar, S., Larijani, B., & Abdollahi, M. (2005). A review on the role of antioxidants in the management of diabetes and its complications. *Biomedicine & Pharmacotherapy*, *59*(7), 365-373.

Ramachandran, P. (2006). The double burden of malnutrition in India. *FAO Food and Nutrition Paper (FAO)*, 99-161. Available at: ftp://ftp.fao.org/docrep/fao/009/a0442e/a0442e00.pdf. Accessed 29 March 2017.

Reddy, K. S. (2012). Universal health coverage in India: the time has come. *The National Medical Journal of India*, *25*(2), 65-67.

Samuel, P., Antonisamy, B., Raghupathy, P., Richard, J., & Fall, C. H. (2012). Socio-economic status and cardiovascular risk factors in rural and urban areas of Vellore, Tamilnadu, South India. *International Journal of Epidemiology*, *41*(5), 1315-1327.

Shetty, P. S. (2002). Nutrition transition in India. *Public health nutrition*, *5*(1a), 175-182.

Shi, Z. M., Hu, X. S., Yuan, B. J., Hu, G., Pan, X. Q., & Holmboe-Ottesen, G. (2008). Coexistence of anaemia and the metabolic syndrome in adults in Jiangsu, China. *Asia Pacific Journal of Clinical Nutrition*, *17*(3), 505-513.

Subramanian, S. V., Perkins, J. M., & Khan, K. T. (2009). Do burdens of underweight and overweight coexist among lower socioeconomic groups in India? *The American Journal of Clinical Nutrition*, *90*(2), 369-376.

Sudha, V., Radhika, G., Sathya, R. M., Ganesan, A., & Mohan, V. (2006). Reproducibility and validity of an interviewer-administered semi-quantitative food frequency questionnaire to assess dietary intake of urban adults in southern India. *International Journal of Food Sciences and Nutrition*, *57*(7-8), 481-493.

Thompson, K. H., & Godin, D. V. (1995). Micronutrients and antioxidants in the progression of diabetes. *Nutrition Research*, *15*(9), 1377-1410.

Thow, A. M., Kadiyala, S., Khandelwal, S., & Menon, P. (2016). Toward Food Policy for the Dual Burden of Malnutrition: An Exploratory Policy Space Analysis in India. *Food and Nutrition Bulletin*, *1*, 14.

Venkatachalam, J., Prasad, V., Muthu Kumar, T., Samuel, A. K., & Singh, Z. (2016). Prevalence and determinants of systemic hypertension among 15-year and older respondents in a rural area of Kancheepuram district, Tamil Nadu—a cross-sectional study. *International Journal of Medical Science and Public Health*, *5*(7), 1433-1438.

Weinert, C., & Boik, R. (1995). MSU Rurality Index: Development and evaluation. *Research in Nursing and Health,18*, 453-464.

World Health Organization. (2000). The Asia-Pacific perspective: Redefining obesity and its treatment. Available at: http://www.wpro.who.int/nutrition/documents/docs/Redefiningobesity.pdf. Accessed 4 March 2017.

World Health Organization. (2005). WHO STEPS surveillance manual: the WHO STEPwise approach to chronic disease risk factor surveillance. Available at: http://www.who.int/ncd_surveillance/en/steps_framework_dec03.pdf. Accessed 4 March 2017.

World Health Organization. (2006). Definition and diagnosis of diabetes mellitus and intermediate hyperglycemia. Available at:

http://www.who.int/diabetes/publications/Definition%20and%20diagnosis%20of%20diabetes_new.pdf. Accessed 29 Nov 2013.

World Health Organization. (2010). The global epidemic. IOTF report. Available at: http://www.iaso.org/iotf/ obesity/obesitytheglobalepidemic/. Accessed 10 February 2015.

World Health Organization. (2011). World Health Organization. Global Physical Activity Questionnaire (GPAQ) Analysis Guide. Available at: http://www.who.int/chp/steps/resources/GPAQ_Analysis_Guide.pdf. Accessed 10 November 2013.

World Health Organization. (2013). Report on the global tobacco epidemic.Available at: http://apps.who.int/iris/bitstream/10665/85380/1/9789241505871_eng.pdf?ua=1. Accessed 29 July 2015.

Zaman, M., Patel, A., Jan, S., Hillis, G. S., Krishnam Raju, P. P., Neal, B., & Chow, C. K. (2012). Socio-economic distribution of cardiovascular risk factors and knowledge in rural India. *International Journal of Epidemiology,41*, 302-314.

Zeba, A. N., Delisle, H. F., Renier, G., Savadogo, B., & Baya, B. (2012). The double burden of malnutrition and cardiometabolic risk widens the gender and socio-economic health gap: a study among adults in Burkina Faso (West Africa). *Public Health Nutrition, 15*(12), 2210-2219.

Zimmermann, M. B., Zeder, C., Muthayya, S., Winichagoon, P., Chaouki, N., Aeberli, I. et al. (2008). Adiposity in women and children from transition countries predicts decreased iron absorption, iron deficiency and a reduced response to iron fortification. *International Journal of Obesity, 32*, 1098–1104.

TABLES

Table 6.1: Crude prevalence (%) of malnutrition double burden phenotypes among women (W, *n*=412) and men (M, *n*=341) in a rural population of south India+

Measures of under-nutrition* \ Measures of over-nutrition*	None	Overweight	Obese Class I	Obese Class II	Overweight, total	Pre-diabetes (impaired fasting glucose and/or impaired glucose tolerance)	Diabetes	High blood pressure	Abdominal obesity
None	W: 8.0 M: 16.4	W: 15.3 M: 16.5	W: 19.0 M: 16.2	W: 4.9 M: 1.8	W: 38.6 M: 34.3	W: 9.6 M: 8.3	W: 10.7 M: 12.9	W: 28.8 M: 31.1	W: 42.0 M: 25.2
Underweight	W: 21.0 M: 24.7	-	-	-	-	W: 1.2 M: 1.5	W: 0.7 M: 0.6	W: 3.6 M: 4.7	W: 0 M: 0
Mild anemia	W: 18.0 M: 22.0	W: 2.7 M: 5.0	W: 4.4 M: 3.2	W: 1.2 M: 0.3	W: 8.3 M: 8.5	W: 1.9 M: 1.5	W: 1.9 M: 4.1	W: 3.6 M: 7.9	W: 3.4 M: 1.5
Moderate anemia	W: 35.9 M: 10.8	W: 5.6 M: 1.2	W: 6.6 M: 2.1	W: 1.7 M: 0.3	W: 13.8 M: 3.5	W: 3.4 M: 1.5	W: 3.2 M: 0.6	W: 12.4 M: 2.9	W: 8.7 M: 0.6
Severe anemia	W: 3.4 M: 2.3	W: 0.5 M: 0	W: 0.5 M: 0	W: 0 M: 0	W: 1.0 M: 0	W: 0 M: 0	W: 0.5 M: 0.9	W: 0.2 M: 0.9	W: 0 M: 0
Anemia, total	W: 57.3 M: 35.2	W: 8.3 M: 6.2	W: 11.4 M: 5.2	W: 2.9 M: 0.6	W: 22.6 M: 12.0	W: 5.3 M: 2.9	W: 5.6 M: 5.6	W: 16.3 M: 11.7	W: 13.1 M: 2.1
Stunted	W: 0 M: 0	W: 0 M: 0.8	W: 0.2 M: 1.5	W: 0.2 M: 0	W: 0.4 M: 2.3	W: 0.4 M: 1.2	W: 0.8 M: 0	W: 0.8 M: 1.2	W: 0 M: 0

Abbreviations: BMI, body mass index; CBG, capillary blood glucose; Hb, blood hemoglobin; M, men; W, women
Definitions as follows: Underweight, BMI<18.5 kg/m^2; mild anemia, Hb<130 g/dL for men, <120 g/dL for women; moderate anemia, Hb 110-129 g/dL for men, 110-119 g/dL for women; severe anemia, 80-109 g/dL for men, 70-109 g/dL for women; stunted, <150.5 cm for men, <139.1 cm for women; overweight, ≥23 and <25 kg/m^2; obesity class I, ≥25 and <30 kg/m^2; obesity class II, ≥30 kg/m^2; impaired fasting glucose, fasting glucose CBG ≥7 mmol/L; impaired glucose tolerance, fasting CBG <7 mmol/L and a 2-h post glucose CBG ≥8.9 mmol/L but <12.2 mmol/L; diabetes, proof of previous diagnosis and/or CBG ≥7 mmol/L and/or a 2 hr post prandial CBG value ≥12.2 mmol/L; high blood pressure, systolic blood pressure ≥ 140 mm Hg and/or mean diastolic blood pressure ≥ 90 mm Hg and/or treatment with blood pressure medication; abdominal obesity, waist circumference ≥90 cm for men, ≥80 cm for women
*Note that the same individuals may be counted in more than one cell

Table 6.2: Clinical, sociodemographic, and dietary characteristics (expressed as mean ±standard deviation or percentages) of a random sample of 753 adults (>19 years) from a rural region of south India by diagnostic category of anemia only, overweight or obese only, and co-morbid anemia and overweight or obese

Characteristic	Category 1: Neither Anemia nor overweight (n=252)	Category 2: Anemia only (n=218)	Category 3: Overweight or obese only (n=145)	Category 4: Co-morbid anemia and overweight or obese (n=138)	p-value for trend*
Descriptive characteristics					
Age	44.9 ±15.0	51.5 ±16.1	45.5 ±11.7	46.2 ±13.3	<0.001[1,4,5]
Women (%)	41.7	65.1	49.0	68.1	<0.001[1,3,4,6]
Hypertension (%)	22.4	24.1	41.5	40.1	<0.001[2,3,4,5]
Rurality Index	-0.21 ±1.31	-0.24 ±1.14	-0.94 ±1.41	-1.07 ±1.21	<0.001[2,3,4,5]
Current tobacco consumer (%)	44.1	44.7	34.7	25.7	0.001[3,5]
Muslim (Hindu as referent) religion (%)	3.6	1.8	5.5	5.1	0.24
Wealth and possession attributes					
Wealth index	11.00 ±4.31	9.56 ±4.35	12.17 ±4.81	11.73 ±5.10	<0.001[1,4,5]
Pucca housing (%)	10.7	8.3	20.7	18.8	0.001[2,4,5]
Land ownership (acres)	1.50 ±1.85	1.20 ±1.54	1.21 ±1.86	1.07 ±1.99	0.11
Livestock ownership (%)	51.8	46.3	34.5	25.5	<0.001[2,3,5]
In-house tap water (%)	7.5	5.5	11.7	9.4	0.18
Physical activity habits					
Physical Activity (hours/day of moderate physical activity)	4.55 ±3.66	3.98 ±3.43	3.59 ±3.77	3.38 ±3.77	0.008[3]
Sedentary time (hours/day)	4.06 ±2.50	4.42 ±2.85	4.76 ±2.91	4.9 ±2.70	0.009[3]
Television time (hours/day)	1.33 ±1.26	1.23 ±1.24	1.68 ±1.36	1.81 ±1.33	<0.001[3,4,5]
Labour occupation (%)	54.7	64.5	47.6	44.9	0.001[4,5]
Dietary intake (g/1000 kcal unless otherwise specified)					
Current alcohol consumer (%)	52.3	41.7	49.7	44.2	0.10
Total energy intake (kcal/day)	2436 ±868	2307 ±634	2436 ±694	2353 ±643	0.20
Carbohydrates	179.8 ±15.6	183.2 ±13.3	176.3 ±14.7	176.7 ±12.9	<0.001[4,5]
Protein	25.8 ±2.1	25.3 ±1.8	25.8 ±1.9	25.7 ±1.7	0.03[1]
Total fat	19.2 ±5.5	18.3 ±5.1	20.9 ±5.0	21.3 ±4.8	<0.001[2,3,4,5]
Dietary fibre	22.4 ±5.2	22.6 ±5.3	21.3 ±5.0	20.7 ±4.6	<0.001[3,4,5]
Dairy products	81.0 ±73.0	75.0 ±65.4	81.6 ±65.3	89.2 ±65.1	0.29
Pulses and legumes	26.4 ±11.4	26.2 ±12.1	28.7 ±12.2	29.2 ±10.7	0.005
Meat and poultry	3.8 ±4.9	2.4 ±2.5	3.4 ±03.9	2.8 ±03.9	<0.001[1]
Fruits and vegetables	73.0 ±46.7	68.7 ±42.4	83.3 ±49.0	87.2 ±56.1	<0.001[4,5]
Refined grains	63.6 ±34.3	63.3 ±31.9	71.5 ±27.0	74.4 ±32.7	0.001[3,5]

*P-values are for Pearson's chi square for proportions and one-way analyses of variance (ANOVA) for means

[1]Category 1 versus 2 different to p<0.05 with Sidak pairwise comparison; [2]Category 1 versus 3 different to p<0.05 with Sidak pairwise comparison; [3]Category 1 versus 4 different to p<0.05 with Sidak pairwise comparison; [4]Category 2 versus 3 different to p<0.05 with Sidak pairwise comparison; [5]Category 2 versus 4 different to p<0.05 with Sidak pairwise comparison; [6]Category 3 versus 4 different to p<0.05 with Sidak pairwise comparison

Table 6.3: Clinical, sociodemographic, and dietary characteristics (expressed as mean ±standard deviation or percentages) of a random sample of 753 adults (>19 years) from a rural region of south India by diagnostic category of anemia only, type 2 diabetes only, and co-morbid anemia and type 2 diabetes

Characteristic	Category 1: No anemia nor diabetes (n=351)	Category 2: Anemia only (n=313)	Category 3: Diabetes only (n=46)	Category 4: Co-morbid anemia and diabetes (n=42)	p-value for trend*
Descriptive characteristics					
Age	44.6±14.0	48.7±15.4	48.9±12.7	54.9±13.4	<0.001[1,3]
Women (%)	44.2	67.8	45.7	54.8	<0.001[1,4]
Hypertension (%)	25.8	28.2	56.5	46.3	<0.001[2,3,4]
Rurality Index	0.14±1.77	0.092±1.60	-096±1.96	-0.83±1.49	<0.001[2,3,4,5]
Current tobacco consumer (%)	41.2	37.2	37.0	38.1	0.76
Family history of diabetes (%)	7.7	7.6	36.9	28.6	<0.001[2,3,4,5]
Muslim (Hindu as referent) religion (%)	3.4	2.2	10.9	9.5	0.006[4]
Wealth and possession attributes					
Wealth index	11.38±4.45	10.39±4.71	11.85±5.14	10.50±5.22	0.02
Pucca housing (%)	13.1	11.8	23.9	16.7	0.14
Land ownership (acres)	1.42±1.83	1.22±1.79	1.18±2.04	0.68±1.09	0.06
In-house tap water (%)	7.1	6.4	23.9	11.9	<0.001[2,4]
Physical activity habits					
Physical Activity (hours/day of moderate physical activity)	4.47±3.73	3.92±3.56	2.16±3.00	2.47±3.44	<0.001[2,3,4]
Sedentary time (hours/day)	4.19±2.63	4.53±2.78	5.38±2.87	5.33±2.86	0.007[2,3]
Television time (hours/day)	1.45±1.31	1.49±1.31	1.55±1.29	1.19±1.25	0.57
Labour occupation (%)	53.0	58.8	45.7	42.9	0.09
Livestock ownership (%)	48	39.6	26.1	28.6	0.003[2]
Dietary intake (g/1000 kcal unless otherwise specified)					
Current alcohol consumer (%)	51.6	43.6	50	35.7	0.08
Total energy intake (kcal/day)	2451±829	2349±649	2324±626	2153±519	0.04
Carbohydrates	179.2 ±14.8	181.0 ±13.4	174.1 ±18.2	178.7 ±14.7	0.02[4]
Protein	25.8 ±02.1	25.4 ±01.7	25.0 ±01.9	25.8 ±01.6	0.06
Total fat	19.7 ±5.3	19.4 ±5.2	21.3 ±5.5	20.1 ±5.0	0.16
Dietary fibre	220.0 ±51.6	219.6 ±81.6	220.6 ±108.0	217 ±63.9	0.99
Dairy products	79.2 ±71.4	79.6 ±65.0	95.3 ±58.9	89.2 ±69.3	0.38
Pulses and legumes	27.5 ±11.6	27.5 ±11.9	28.3 ±13.3	27.4 ±09.3	0.97
Meat and poultry	3.7 ±4.5	2.6 ±3.1	3.7 ±4.6	2.5 ±3.2	0.003[1]
Fruits and vegetables	77.0 ±48.3	76.6 ±50.7	74.9 ±43.3	70.4 ±33.1	0.86
Refined grains	67.1 ±32.3	76.6 ±50.7	74.9 ±43.3	70.4 ±33.1	0.86

*P-values are for Pearson's chi square for proportions and one-way analyses of variance (ANOVA) for means
[1]Category 1 versus 2 different to p<0.05 with Sidak pairwise comparison; [2]Category 1 versus 3 different to p<0.05 with Sidak pairwise comparison; [3]Category 1 versus 4 different to p<0.05 with Sidak pairwise comparison; [4]Category 2 versus 3 different to p<0.05 with Sidak pairwise comparison; [5]Category 2 versus 4 different to p<0.05 with Sidak pairwise comparison; [6]Category 3 versus 4 different to p<0.05 with Sidak pairwise comparison

Table 6.4: Factors associated with anemia, overweight, and co-morbid anemia and overweight in a multivariable logistic regression analysis in a sample of adults (>19 years) in rural south India

	Anemia only OR (95% CI)	Overweight only	Co-morbid anemia and overweight
Age (continuous)	1.03 (1.02, 1.05)[a]	1.01 (1.00, 1.03)	1.01 (0.99, 1.03)
Female sex (male as referent)	3.0 (2.03, 4.46)[a]	1.30 (0.82, 2.05)	2.31 (1.39, 3.85)[a]
High caste (Brahmin)	-	3.95 (1.75, 8.93)[a]	3.17 (1.34, 7.49)[a]
Wealth index	-	1.06 (1.01, 1.13)[a]	1.05 (1.00, 1.12)[b]
Rurality index	-	0.69 (0.58, 0.81)[a]	0.69 (0.56, 0.85)[a]
Tobacco consumption	-	-	0.55 (0.32, 0.96)[b]
Livestock ownership	-	-	0.51 (0.29, 0.89)[b]
Meat and poultry intake (g/1000 kcal)	-	-	0.75 (0.61, 0.94)[b]

Only variables associated with one or more outcome level ($p<0.05$) are displayed
The dependent variable is a multi-level outcome: 0=neither anemia nor overweight (referent, not shown); 1=anemia only; 2=overweight only; 3=both anemic and overweight
Definitions as follows: anemia, Hb<130 g/dL for men, <120 g/dL for women; overweight, ≥23 kg/m^2
[a]$p<0.01$; [b]$p<0.05$; [c]$p<0.1$; [d]$p<0.2$

Table 6.5: Factors associated with anemia, diabetes, and co-morbid anemia and overweight in a multivariable logistic regression in a sample of adults (>19 years) in rural south India

	Anemia only, fully adjusted model OR (95% CI)	Diabetes only, fully adjusted model OR (95% CI)	Co-morbid anemia and diabetes, fully adjusted model OR (95% CI)
Age (continuous)	1.02 (1.01, 1.03) [a]	1.02 (1.00, 1.04)[d]	1.08 (1.05, 1.11)[a]
Female Sex (male as referent)	2.73 (1.97, 3.79) [a]	1.43 (0.61, 2.11)	1.04 (0.49, 2.20)
Scheduled caste or tribe (Y/N)	-	2.89 (1.21, 6.90)[b]	-
Seasonal migrant (Y/N)	0.54 (0.31, 0.94)[b]	-	-
Livestock ownership (Y/N)	0.68 (0.49, 0.94) [b]	-	-
Rurality index	-	-	0.75 (0.57, 0.98)[b]
Family history of diabetes (Y/N)	-	4.17 (1.80, 9.62)[a]	4.86 (1.86, 12.70)[a]
Physical Activity (h/day moderate activity)	-	0.85 (0.76, 0.96)[a]	-
Body Mass Index (standardized)	-	1.87 (1.25, 2.81)[a]	2.14 (1.45, 3.14)[a]
Waist circumference (standardized)	-	1.68 (1.09, 2.57)[b]	-
Meat and poultry intake (g/1000kcal)	0.87 (0.78, 0.98)[b]	-	-

Only variables associated with one or more outcome level ($p<0.05$) are displayed
The dependent variable is a multi-level outcome: 0=neither anemia nor diabetes (referent, not shown); 1=anemia only; 2=diabetes only; 3=both anemia and diabetes
Definitions as follows: anemia, Hb<130 g/dL for men, <120 g/dL for women; diabetes, proof of previous diagnosis and/or CBG ≥7 mmol/L (≥126 mg/dl) and/or a 2 hr post prandial CBG value ≥12.2 mmol/L (≥220 mg/dL);
[a]p<0.01; [b]p<0.05; [c]p<0.1; [d]p<0.2

CHAPTER SEVEN:

AN ANALYSIS OF THE FOOD ENVIRONMENT AND ITS IMPACT ON FOOD CHOICE AND CONSUMPTION IN RURAL SOUTH INDIA

ABSTRACT

Background and Objectives: Diets high in refined grains and low in vegetables are associated with micronutrient deficiencies, obesity, and cardio-metabolic diseases. Such dietary patterns may therefore be relevant to the double burden of malnutrition in India. The objectives of this study were to identify characteristics of the food environment that influence food choice and consumption, and to determine associations between these characteristics and individual-level consumption of refined grains and vegetables, and individual-level consumption of a diet high in refined grain and low in vegetables.

Methods: A mixed methods study design was used. Qualitative data were collected by household interviews (n=61) and analyzed using a thematic content analysis to identify characteristics of the food environment that affect food choice and consumption by altering one or more of the consumption drivers: *availability*, *affordability*, *convenience*, and *desirability* of foods. Following this, data from a cross-sectional survey and food frequency questionnaire (n=753) were analyzed using multivariable linear and logistic regressions to determine associations between food environment characteristics and intake of refined grains and vegetables and a diet simultaneously high in refined grain and low in vegetables.

Results: Qualitative interviews revealed that demographic factors (age, sex, education, literacy, migration), socio-economic-cultural factors (household size, religion, caste, wealth), geography (rurality and distance to amenities), agricultural activities (type of agriculture, livestock ownership), exposure to media (through television), and food entitlements through the Public

Distribution System were all perceived to influence food intake through one or more drivers of food choice and consumption. In a multivariable model, the following variables were associated (positively: +, or negatively: -) with energy-adjusted intake of refined grains: female gender (+), higher caste (+), higher education (+), television ownership (+), older age (-), increased rurality (-), and agriculture as primary occupation (-). In a multivariable model, the following variables were associated with energy-adjusted intake of vegetables: high caste (+), time spent watching television (+), older age (-), and increased distance to food market (+). Finally, the following variables were associated with a diet high in refined grain and low in vegetables [OR (95% confidence interval]): older age [0.99 (0.97, 1.00)], agriculture as primary occupation [0.67 (0.47, 0.96)], and vehicle ownership [1.53 (1.03, 2.26)].

Conclusion: These results are important to understand distal drivers of food choice and consumption that may be contributing to the double burden of malnutrition.

7.1 Introduction

India is currently facing a "double burden" of malnutrition, characterized by persistent under-nutrition and micronutrient deficiencies coexisting with rising incidence of diet-related non-communicable diseases (NCDS) (Gillespie & Haddad 2003). NCDs have quickly become the leading national cause of death in India, accounting for 45% of disability-adjusted life years (DALYs) and 60% of all mortalities (Institute for Health Metrics and Evaluation 2013). While previously perceived as diseases of urban affluence, prevalence of NCDs has been rapidly rising amongst poor, marginalized, and rural populations, resulting in one of the highest country-wide prevalences in the world. Review studies demonstrate that prevalence of obesity has risen by 127% in the past 12 years, and now affects approximately one in three urban adults and one in five rural adults (Pradeepa et al. 2015). Prevalence of obesity-related NCDs is similarly high; coronary heart disease affects between 4-13% of urban residents and 2-5% of rural residents (Gupta et al. 2008). Type 2 diabetes mellitus affects upwards of 13-18% of individuals in urban areas (Sen et al. 2015), and recent studies in rural south India have exposed regional prevalence of 10-16% (Little et al. 2016; Rao et al. 2010; Vijayakumar et al. 2009).

The NCD epidemic in India has occurred against a backdrop of persistent under-nutrition. An anthropometric survey conducted by the National Institute of Nutrition indicated that measures of under-nutrition amongst rural women and children are some of the highest in the world (Cohen 2007; Deaton & Drèze 2009; Guha-Khasnobis and James 2010). While acute malnutrition is rare, chronic under-nutrition (e.g. stunting) is common, particularly among children (Bose et al. 2007). In addition, approximately 34% of adult men and 36% of adult women are underweight (IIPS 2007). Meanwhile, prevalence of micronutrient deficiencies is high, especially in rural areas (Jha et al. 2009; Pathak et al. 2004). Iron-deficiency anemia affects 75% of women and 55% of men. Vitamin A deficiency affects 44-50% of preschool children (WHO 2009). Several national and regional studies have reported inadequate intake of zinc and iodine (Singh et al. 1998; Stein et al. 2007; Toteja et al. 2004). Such statistics, combined with the epidemics of obesity and NCDs, expose the extent of the double burden of malnutrition in India. Importantly, this double burden is not limited to co-occurring under- and over-nutrition at the national level. In fact, it is increasingly common that markers and complications of both under- and over-nutrition occur within the same household (Garrett & Ruel 2003) and individual (Jones et al. 2016).

The etiology of the double burden of malnutrition is complex. Genetic, lifestyle, and dietary factors interact to increase risk of micronutrient deficiencies, stunting, underweight, overweight, and nutrition-related NCDs (Upadhyay 2012). Recent lifestyle and dietary changes are aggregately termed ‘the nutrition transition’, a phenomenon characterized by increased sedentarism, urbanization, and consumption of ultra-processed foods high in sugars and unhealthy fats, but low in essential vitamins and minerals (Drewnowski & Popkin 1997). In India, researchers investigating the health effects of the nutrition transition have emphasized the risks of over-consumption of refined grains and under-consumption of vegetables - trends that have been associated with obesity (He et al. 2004; Liu et al. 2003) and other cardio-metabolic diseases (Dauchet et al. 2006; Mohan et al. 2010; Radhika et al. 2009). While intake varies by region and socioeconomic status, national data suggest refined grains are rapidly replacing coarse cereals (Misra et al. 2011). Meanwhile, average vegetable consumption remains well below levels recommended by the World Health Organization and the National Institute of Nutrition in India (National Institute of Nutrition 2011; WHO 2015). Such dietary patterns may partially explain the co-existence of over- and under-nutrition within populations, households, and individuals.

While dietary patterns play a critical role in the rising double burden of malnutrition, analyses of food consumption patterns and implication for health outcomes in India often occur in urban contexts and overlook the existence and effects of the nutrition transition in rural areas, where 70% of the Indian population live (Government of India 2011). Very few studies have focused on the myriad of environmental factors that influence food choices and food consumption, and how these may be contributing as drivers of shifting food patterns associated with the nutrition transition. The food environment is defined as the “collective physical, economic, policy and socio-cultural surroundings, opportunities and conditions that influence people’s food and beverage choices and nutritional status”, and includes such factors as food composition, food labeling, food promotion, food prices, food provision in schools and other settings, food availability and trade policies affecting food availability, price, and quality (Swinburn et al. 2014). A number of recent of studies on food environments have broadened our understanding of the impact of food environments on nutrition, particularly within the context of obesity and nutrition-related NCDs in developed countries. Policymakers and researchers in the US (Walker et al. 2010), Canada (Health Canada 2013), New Zealand (Swinburn, Dominich, & Vandivijevere 2014), Australia (Campbell et al. 2007; Campbell et al. 2006), and Europe (Nicholas et al. 2013) have undertaken evaluations of the food environment and its impact on food choices and subsequent risk of NCDs. However, relatively few studies have focused on evaluating food environments in low- and middle-income countries (LMICs) in Latin America, Africa, and Asia (Clark et al. 2012). This represents a substantial gap and a crucial research area for developing evidence-based policy and public health messaging in LMICs that are experiencing nutrition transitions and associated disease burdens.

We undertook a mixed methods study in a rural region in northwestern Tamil Nadu, south India, to examine the impact of the food environment on food choice and consumption. In elucidating the food environment, we employed a framework adapted from Herforth and Ahmed (2015), in which the food environment influences food consumption through the relative *availability*, *affordability*, *convenience,* and *desirability* of different foods. Herforth and Ahmed (2015) call these "characteristics of actual foods", and we will refer to them as "drivers of food choice and consumption", or simply "consumption drivers". Using these consumption drivers as a starting point, we can assess potential causes ('upstream' environmental factors, including physical, economic, policy, and socio-cultural dynamics) and potential effects ('downstream' patterns of food choice and consumption, and subsequent health implications) of the availability, affordability, convenience, and desirability of different foods (Figure 7.1).

This article has three primary objectives. First, we use qualitative methods with a sample of 61 adults to identify characteristics of the food environment that are perceived to affect the local relative availability, affordability, convenience, and desirability of foods. Second, we explore food frequency data from a sample of 753 randomly-selected adults (>19 years) to determine average intakes of selected food groups, macronutrients, and micronutrients, and compare these values to recommended dietary allowances (RDAs) to determine excesses and deficits in the diets of the study population. Third and finally, we explore the effect of environmental factors on consumption of (1) refined grains, (2) vegetables, and (3) combined high refined grain and low vegetable intake. This study will elucidate the impacts of the food environment in Tamil Nadu and contribute to our knowledge of environmental factors influencing food intake vis-à-vis the nutrition transition in rural India.

7.2 Methods

This concurrent mixed methods (qualitative and quantitative) study was conducted in four rural *panchayats* (townships) in the Krishnagiri district of Tamil Nadu. Local languages were *Kannada* and *Tamil*. Prior to the study, we obtained ethics approval for the study from a Canadian university ethics board (ethics certificate number 12MY019). Prior to the quantitative study, we also sought and were granted permission from the High Commission of India in Ottawa, Canada and local authorities, including the *panchayat* (township) councils, the *taluk* (regional) police supervisor, the district police chief, the district medical officer, local hospital staff, and the Krishnagiri district Foreign Registration Office. Informed verbal consent was obtained from all participants prior to their enrollment.

We employed an iterative research design, whereby qualitative interviews were first conducted and analyzed to develop a list of quantifiable environmental factors that characterize the local food environment and influence the relative availability, affordability, and desirability of foods. Following this, we analyzed the associations between environmental factors and consumption of refined grains and vegetables. Refined grain and vegetable intake were selected due to their relevance to the nutrition transition and the double burden of malnutrition. This study was part of a larger project, entitled "Revalorizing Small Millets in Rainfed Regions of South Asia" (RESMISA), an interdisciplinary and multinational research project. The study region was previously selected as a study site for RESMISA.

7.2.1 Qualitative study

We developed a semi-structured interview guide to capture in-depth responses regarding: (1) perceptions of nutrition and its contributions to health; (2) recent dietary change; and (3) factors contributing to dietary choices and food intake. Interview questions were open-ended. Questions were informed by immersive engagement in the research villages, input from local research assistants, and assistance from local RESMISA partners. The guide was written in English and translated to *Kannada* and *Tamil* by trained research assistants.

We conducted interviews with 61 individuals, each from different households, in 17 villages from four *panchayats*. Households were recruited by convenience and snowball sampling. The research team determined the final sample size after reaching a point of perceived data saturation. Prompts were used to encourage respondents when they had difficulty understanding or answering questions. Follow-up questions were used to clarify pertinent points and encourage a tone of conversation rather than interrogation. Responses were concurrently translated to English for the benefit of the first author, who was present at all interviews. All interviews were audio recorded, and recordings were transcribed the same day as the interview.

Transcripts were processed in the software package NVivo (QSR International, Melbourne, AU) using a thematic content analysis with pre-defined themes for drivers of food choice and consumption. First, we identified codes relating to (1) perceptions of foods themselves (e.g. food quality, harmful vs. healing foods); (2) perceived dietary changes that occurred within the respondents' lifetimes; and (3) factors impacting food availability, affordability, desirability, and/or convenience. Codes were then grouped into themes, and each passage was assessed for consistency within its theme. Using this process, we identified a number of important environmental factors that were perceived to influence drivers of food choice and consumption, and included these environmental factors in the quantitative analysis.

7.2.3 Quantitative study

7.2.3.1 Sampling frame and sample selection

We used cross-sectional data from a sample of 753 adults from two of the same *panchayats* enrolled in the qualitative study. A randomized two-stage sampling method was used. First, we systematically randomly sampled 8% of the households in each of 17 villages by mapping each village, numbering the houses, and selecting each 12th household. We approached selected households and employed WHO's Kish method (WHO 2005) to select one non-pregnant adult (age >19 years) household member for the study. If the selected member refused, we removed them from the list of occupants and employed the Kish method again until the selected member confirmed their willingness to participate.

7.2.3.2 Measurement and definitions

Following enrollment in the study, we made a follow-up appointment with each participant. We collected basic socio-demographic information using a quantitative survey that asked questions about age, sex, caste, education (years of formal education), occupation, land ownership (acres), household size (number of members), ration entitlements through the Public Distribution System (the national food rationing program, described below), asset ownership (for the wealth index, described below), and physical activity.

Dietary intake was assessed using a semi-quantitative food frequency questionnaire (FFQ) designed by the Madras Diabetes Research Foundation (MDRF) and previously validated for use in Tamil Nadu. Detailed descriptions of the FFQ, as well as results of a study on its reproducibility and validity, are published elsewhere (Sudha et al. 2006). Interviews were conducted by nutritionists who were trained by MDRF ensure accuracy and consistency before the study began. The interviewer asked each participant to estimate the frequency (number of times per day/week/month/year) of consumption of 223 locally-available food items. The FFQ was paired with a food atlas, which was used for visual prompts and portion estimations.

Dietary intake data were analyzed using EpiNu ® (MDRF, Chennai: TN) to estimate the total average kilocalories consumed per day, as well as grams per day consumption of food groups (e.g. refined grains, whole grains, meat and eggs, milk and milk products, vegetables, and fruits), specific foods (e.g. rice, millets, sugar, sodium), macronutrients (e.g. carbohydrates, protein, fats, and fibre), and micronutrients (e.g. iron, calcium, and vitamin C). Refined grains included foods that had the bran and germ layer removed, and included polished white rice, semolina, and white flour (in bakery items, white bread, and breakfast cereals). Vegetable intake included consumption of leafy vegetables and other vegetables (e.g. tomatoes, carrots, onions, *brinjal* (eggplant), gourds, and lesser-known vegetables) but excluded roots and tubers. Refer to Appendix 2 for a full list of dietary intake variables.

Socioeconomic status (SES) was assessed with an asset-based wealth index using a subset of 13 of 29 questions taken from the Standard of Living Index developed by the

International Institute for Population Sciences (IIPS) for use in their National Family and Health Surveys (NFHS) (Table A1.1, Appendix 1) (IIPS 2007). Assets were selected for relevancy to the study population and were weighted for a maximum score of 41 using weights developed by the IIPS, based on a priori knowledge of their correlation with other measures of SES (Ebrahim et al. 2010). Caste was categorized as low caste (comprised of scheduled castes and scheduled tribes), middle caste (comprised of other backward castes and most backward castes), and high caste (Brahmin caste).

Physical activity was assessed using a global physical activity questionnaire (GPAQ framework (WHO 2011). Activity scores provided a total measure of Metabolic Equivalent (MET) minutes per week. Values were scaled to hours per day of moderate physical activity. We calculated a rurality index (RI) value for each individual by summing the standardized values of (1) number of households in home village (assigned full weight) and (2) distance to primary health center (in kilometers, assigned half weight). RI values were further standardized to a mean of zero and a SD of one. A higher RI value therefore represented a combination of a lower population density and a greater degree of isolation.

7.2.3.3 Data Analysis

We completed all statistical analyses in STATA Version 13.0 (StataCorp, College Station, TX). We determined sex-specific average intakes (g/day) of various food groups, macronutrients, and micronutrients. Two primary dietary intake variables were selected for subsequent analyses; namely, intake of (1) refined grains and (2) vegetable intake, due to the relevance of these foods to the double burden of malnutrition. In all regression analyses, to avoid confounding by sex, body size, metabolic efficiency, and physical activity, dietary intake variables were adjusted for total energy consumption by scaling to grams per 1000 kilocalories (g/1000 kcal) (Willett 1998).

Based on the qualitative results, we identified several environmental characteristics that affect one or more of the drivers of food choice and consumption (availability, affordability, desirability, and/or convenience of foods). These characteristics included caste, PDS entitlement, rurality index, vehicle ownership, land ownership, type of agriculture (if applicable), distance to convenience food vendors, distance to food market, television ownership, time spent watching television, age, education, sex, and household size. Mean values (expressed as means +/- SD or percentages) of characteristics were examined across quartiles of refined grain and vegetable intake. One-way analyses of variance and Pearson's Chi Square tests were used to identify significant differences across quartiles of intake for continuous variables and proportions, respectively. If the test statistic was significant ($p<0.05$), we used a Sidak pairwise comparison to determine which categories were different from each another.

We built two separate linear regression models using a backward stepwise process to determine factors associated with (1) refined grain intake and (2) vegetable intake. First, we identified factors associated with each outcome variable to $p<0.2$. Identified factors were then included in initial multivariable linear regression models. We methodically eliminated non-significant variables using a p-value cut-off of 0.05 from each model. We assumed no confounding if coefficients of remaining variables changed by less than 20% after removal of the variable. When linear regression violated the assumptions of linear models, including normality of residuals and homoscedasticity, we used the Box Cox function in STATA to test various outcome transformations and adjusted models as necessary. If no transformations resulted in improved diagnostics, we used robust standard errors when reporting the significance of each predictor, as suggested by Pires and Rodrigues (2007).

To evaluate the relationship between factors influencing the food environment and a diet conducive to the individual-level double burden of malnutrition, we used a backward elimination process to build a multivariable logistic regression that assessed the associations between environmental characteristics and a concurrent high refined grain and low vegetable (HRGLV) diet. We identified individuals that were in the lowest 50th percentile of energy-adjusted vegetable consumption *and* the highest 50th percentile of energy-adjusted energy consumption, and designated these individuals as HRGLV. First, age- and sex-adjusted bivariate models were employed to identify factors associated with HRGLV at $p<0.2$. Identified factors were then included in initial multivariable logistic regression models. We methodically eliminated non-significant variables one at a time beginning with the highest p-value until all remaining variables were significant at p-value 0.05. We assumed there was no confounding if coefficients of remaining variables changed by less than 20% after removal of variable. All models were adjusted for age and sex.

7.3 Results

In total, 61 individuals (26.2% women), each representing a different household, participated in the qualitative interviews. For the quantitative study, 753 individuals (54.7% women) participated, of whom 752 completed a FFQ. Response rate was 100% for the qualitative study and 93.2% for the quantitative study. Among the entire study population, the literacy rate was 34.8% based on criteria defined by the Tamil Nadu District-Level Household Survey (IIPS 2008). Individuals had completed, on average, three years (SD 4.2) of formal schooling.

7.3.1 Qualitative study

During the semi-structured interviews, participants shared a number of perceptions relating to food, nutrition, and factors affecting the food environment. All respondents believed that diets had changed rapidly in the past thirty years. Almost all (52/61) stated that diets were "getting worse" for health, despite reporting that food shortages were not a problem. Most participants insisted that, in the past, diets were more "natural", "ayurvedic", and "energizing", and comprised of a "higher diversity" of foods. Generally, participants viewed traditional foods as "good", "nourishing", "hygienic", and "healthy". Foods identified as beneficial included *ragi* (finger millet), *cholam* (sorghum), *avarai* and *thobarai* (pulses), meat (chicken and mutton), fruits, and vegetables. By contrast, "new", "urban", or "outside" foods (non-local foods) were perceived as less trustworthy, and commonly viewed as "bad", "unhealthy", "not suitable", "unnatural", and "unhygienic", leading to "health problems", "low energy", "sickness", and "bad digestion". Such foods included rice, sugar, palm oil, sweets, snack foods, and alcohol. Participants commonly cited chemical pesticides and preservatives as a primary reason for the poor quality of "outside" foods. One male participant explained the changing quality of available foods,

> *"20 years ago, we ate natural foods that made us healthy. Now people's food has changed. We use fertilizers and insecticides. Now we are not as healthy. In the past, we ate a lot of ayurvedic foods like leaves and ragi, waradu, arca, and samai [millet crops]. We used to use natural fertilizer, but now we use chemical fertilizer. It's changed – the use of fertilizers, and the climate, it's all changed, which affects people's health. Before, diabetes, anemia, and joint pain weren't a problem, but now, our health is getting worse."* [Note: the participant stated this quotation *after* a discussion about diabetes, anemia, and joint pain, so these were not entirely unprompted]

Another participant explained her perceptions about the relative healthfulness of available foods, *"I know that ragi is good for our health. We eat leaves and vegetables from the forest, which are good for us. We also get honey from the forest, and this is good for our health. Meats are also good for us – we hunt forest animals, and we eat mutton too. We eat fish sometimes, which are good for our health. We eat some rice, but the digestion is very low – it gives us difficulties. And when we eat it, we can't do a lot of work."*

7.3.1.1 Factors comprising the food environment

Participants identified a number of environmental factors that affect the availability, affordability, convenience, and desirability of food. Many of these factors affect more than one driver of food choice and consumption.

7.3.1.1.1 The Public Distribution System

One of the primary drivers of food availability, affordability, and convenience is the Public Distribution System (PDS), a large-scale government food-rationing program. At the time of data collection, below poverty line families in the research site were eligible to receive between 20 and 35 kg of free rice per month per household, as well as below-market prices on cooking oil, kerosene, sugar, and occasionally pulses. Entitlements were distributed through "government shops" [officially: Fair Price Shops] and varied based on caste, household size, and land holdings, as well as special circumstances such as HIV+ status, homelessness, and disability (Tamil Nadu Civil Supplies Corporation 2011). Fair Price Shops were open one day per month and were common in the research site; no participant lived more than 5 km from a shop. The PDS is perceived as an important driver of household food security, as described by the following respondent,

"The program is very useful to us. Of course it's useful. I'm not sure how we would eat if it didn't exist. We don't have any lands that are good for growing grain, so we need to get rice through the government shop. We eat more because of the PDS – we are able to afford more food."

Nonetheless, despite its benefits for food security, the PDS has also altered food consumption habits to favour the food that it supplies (refined rice in particular), often in lieu of "healthier" traditional foods. Over 25% of participants thought the quality of food provided by the PDS was "poor". As explained by one respondent,

> *"In comparison to our traditional foods, the [PDS] government rice is like mud. The older grain varieties, like samai [little millet], thennai [foxtail millet], and varagu [kodo millet] give us strength – they are better quality, healthier, and stronger. Don't compare! The government [PDS] rice is like mud. But since it is free, we must eat it. That way, we can sell the grains we grow [ragi – finger millet], and get a little money."*

Not only does access to the PDS affect the availability and affordability of foods, but it also affects the convenience of food. Several respondents explained that, due to the relatively short preparation time of rice, it is becoming increasingly popular in the research site and surrounding areas. One respondent explained,

> *"We used to eat many more types of dishes with ragi. We made* [millet] *dosai, roti, and more. Now I eat more rice – I eat rice every day, because it's easier to prepare and I am working all day long."*

Some individuals sold their PDS entitlements to others with fewer (or no) entitlements, thus making a profit and reducing the portion of household entitlements that are actually consumed within the household. While individuals admitted that this was common, most were hesitant to discuss it since such activities are illegal, and if caught, households may have their ration cards confiscated.

7.3.1.1.2 Agricultural patterns

Many participants described how shifting agricultural patterns in the study region impacted local availability of foods. Various reasons were provided for agricultural change, including seed availability, technological advances (e.g. availability of pesticides), climate change, rising labour wages, and the rising popularity of labour migration, which reduces the availability of on-farm labour. Generally, changes were characterized by declining diversity of coarse cereals and rising popularity of mono-cropping (usually *ragi*) and commercial (cash) cropping (e.g. coconuts, ground nuts, tomatoes, and bananas). As described by one participant,

> *"In the past, we grew and ate all types of crops – many types of millets…We didn't get any diseases from those, they were so healthy….but we can't grow those [millets] anymore because we don't get enough rain. Even if we could grow them, we couldn't harvest them, because they are difficult to harvest and we cannot pay for labour. Many people have converted their field to commercial crops like bananas and ground nuts. We still grow ragi, because it gives a lot of quantity [high yield] and it doesn't need as much rain. So now, we only eat ragi and government [PDS] rice. Everyone eats mostly rice."*

Several smallholder farmers explained that urban demand for *ragi* was increasing, driving up prices and increasing incentive for farmers to sell their crops instead of consuming them. Many participants suspected that this trend, in addition to the increasing popularity of farmers to convert their land to commercial crop production, was driving the export of local crops and increasing the dependence on food obtained through the PDS, as well as local markets and shops.

In the study region, agriculture patterns were overwhelmingly rain-fed, meaning very few landholders had access to irrigation and took advantage of only one growing season. This constrained the capacity of farmers to produce a diversity of crops, and most only produced *ragi, cholam* and pulses (including, most frequently, *avarai* and *thobarai*). Vegetable and commercial crop production required irrigation, and fewer than 10% of landholders produced these crops. As explained by one landholder,

> *"The rains come only once, so we plant seeds when the rain comes and harvest in the dry season. I grow* ragi, avarai, thobarai, and ground nuts. *These crops don't need irrigation. Some people have irrigation and they can grow bananas, coconuts, tomatoes…but most do not."*

7.3.1.1.3 The effects of technology and a shifting food culture

Technology, such as the recent popularity of vehicles and televisions, has had a substantial impact on the local food environment. When asked, "has technology like cellular phones, vehicles, and televisions made your life better or worse?", responses were mixed. Due to the isolated location of many study villages, purchasing a vehicle allows access to food markets and shops that would otherwise require lengthy travel on public transportation. As one respondent explained,

> *"My son went to Bengaluru [nearby city] to work for a time, and he made enough money to buy a motorcycle. It's stressful for me, since they are dangerous and I worry that he may be in an accident. But when he is here, it is good, because he can drive me to [market town] regularly for food, and we can buy fresh food, like vegetables, more often. Before, when we had no vehicle, I only went to [market town] once per month to buy food."*

Vehicles may therefore improve access to fresh and healthy foods. However, they also may have the effect of simultaneously improving access to snack foods, street vendors, and restaurants that can only be found in larger towns. As further explained by the same woman,

> "*My son rarely eats at home anymore! He is always in [market town] eating at the hotels [restaurants]. I'm worried, because he doesn't like ragi anymore, and it will be bad for his health."*

This story also touches on the potential effects of seasonal labour migration, which has become an increasingly popular livelihood strategy in the research site. While we didn't speak directly to any migrants, several individuals lived in households in which one or more of the members had migrated for work, and expressed concern that migration had an impact on food preferences. As explained by one man, and the head of his household,

> "*My son goes to Hosur [a nearby city] to work at a brick factory. He lives with other employees and they always eat in a hotel [restaurant] – he eats biryani and other foods. I know he prefers rice to all other foods. Now, when he comes home, he doesn't even eat ragi anymore! A lot of the young people are like this."*

Food preferences were also impacted by advertising, and in particular, television advertising. Televisions have become extremely common in the research site, largely due to a 2006 government scheme that distributed free televisions to rural households. Advertising may increase the desirability sugar-sweetened beverages, snacks, and other packaged foods. Several respondents reported television advertising as influential on their family's food choices. One young woman who had recently given birth shared the following story,

> *"I saw on the television that there was formula powder that can be mixed with water that is even healthier than breast milk. So I bought it, because I was worried that my breast milk might not be good quality, since it's the dry season and I haven't been eating… many vegetables."*

Similarly, television programs may influence people's dietary choices by altering cultural norms. As stated by one woman,

> *"We use the television for entertainment, not for education. Television sometimes teaches people bad habits, like smoking and drinking. It makes people want to do those things when we seen them on television."*

Not all participants felt that television was "not for education". For example, one man told us,

> *"Televisions are very useful, because I can watch the news and learn about the world. I can also learn about health issues, so I am becoming more educated."*

Migration, exposure to advertising, and other socio-cultural factors have resulted in changes in food preferences among younger generations in particular. Several respondents expressed disdain that their children and other young people had no interest in consuming traditional foods, and preferred "new" foods, which are perceived as more palatable. As stated by one individual,

> *"Children don't like bland food… so they are eating more 'exciting' foods like snacks, sugar, and everything else. Children are eating new foods like pizza, foods that are more interesting to eat. They don't want to eat old foods."*

Finally, the opportunity cost of food preparation influences food consumption. Some individuals (generally women) expressed a tendency to prepare rice and other more convenient foods instead of traditional dishes, which tended to be more labor-intensive. As stated by one woman,

> *"I used to eat natural millets…but now I eat PDS rice. I used to eat more foods with ragi – I would make* roti, chapathi, *– but now I have replaced [those foods] with rice because it is much easier to cook. We are lazy now."*

7.3.2 Quantitative study

Quantitative results were based on a sample of 753 adults, including 412 (54.7%) women and 341 (45.3%) men. Average age of participants was 47 (SD 14.7). Many (53.9%) participants relied on agriculture as their primary occupation. Several (10.4%) relied on seasonal labour migration.

Consumption of food groups, macronutrients and micronutrients by sex are displayed in Table 7.1. Males included in the study consumed more calories, on average, than women ($p<0.001$). Consumption of coarse cereals, milk products, meat products, roots and tubers, and sugar were higher among males than females. Consumption of all macronutrients (protein, carbohydrates, fats, and dietary fibre) was higher for males. Consumption of all micronutrients except calcium was not significantly different between males and females. After adjustment for energy intake, men consumed relatively more coarse cereals and milk products than women ($p<0.05$) (Table A3.1, Appendix 3).

Based on the qualitative interviews, we identified several environmental factors that were perceived to influence food choice and consumption through one or more of the four drivers of food choice and consumption (availability, affordability, convenience, and desirability of foods). These factors are categorized, broadly, as: individual-level factors; socioeconomic-cultural factors; PDS entitlements; location of household; agricultural factors; and exposure to advertising (Table 7.2).

Various characteristics of the food environment by quartile of energy-adjusted refined grain intake are presented in Table 7.3. In unadjusted analyses, several characteristics were significantly different between the lowest and highest quartile. Individuals in the highest quartile of refined grain consumption were more likely to be women and high caste compared to the lowest quartile. PDS entitlements were significantly lower in the highest quartile, suggesting that availability of refined PDS grain was negatively associated with its consumption. Individuals from households with larger land holdings and those participating in subsistence agriculture were less likely to consume refined grain. Rurality (assessed as the rurality index, distance to convenience food vendors, and distance to food market) was greater in the lowest quartile of grain consumption in comparison to the highest quartile, indicating that refined grain consumption increases with improved access to markets and vendors. Individuals in the highest quartile of refined grain consumption were more likely to own a television, and watched more television on average, than those in the lowest quartile. Finally, individuals in the highest quartile of refined grain consumption were relatively better educated and younger than those in the lowest quartile.

After multivariable adjustment in linear regression analyses, a number of characteristics were associated with energy-adjusted refined grain intake (Table 7.4). The final model had an adjusted R^2 value of 0.20, indicating that 20% of the variability in refined grain intake was explained by the independent variables included in the model. The untransformed model was heteroscedastic using a Cook-Weisberg Test and lacked normality of standardized residuals using a Shapiro-Wilks test. After assessment of standardized residuals with a normal probability plot and testing transformations using the Box Cox function in STATA, we determined that no transformations improved the model diagnostics, and reported robust standard errors. Age, high caste, education, and television ownership were positively associated with refined grain intake. Meanwhile, physical activity, rurality, and participation in agriculture were negatively associated with refined grain intake.

Various characteristics of the food environment by quartile of energy-adjusted vegetable intake are presented in Table 7.5. Individuals in the lowest quartile of vegetable intake were, on average, older and less educated compared those in the highest quartile. Individuals in the highest quartile of vegetable intake were more likely to be from a higher caste compared to those in the lowest quartile. Individuals in the highest quartile of vegetable intake were less likely to own land and participate in agriculture compared to those in the lowest quartile. Rurality (assessed using the rurality index and distance to food vendors/markets) was significantly higher among individuals in the lowest quartile of vegetable intake, indicating that access to markets may improve vegetable intake. Finally, individuals in the highest quartile of vegetable intake were more likely to own a television, and watched more television on average, compared to those in the lowest quartile.

After multivariable adjustment in a linear regression analysis, a number of characteristics were associated with energy-adjusted vegetable intake (Table 7.6). The adjusted R^2 value of the model was 0.035, indicating that 3.5% of the variability in energy-adjusted vegetable consumption was accounted for by the independent variables. The untransformed model was heteroscedastic using a Cook-Weisberg Test and lacked normality of standardized residuals using a Shapiro-Wilks test. Using the Box Cox function in STATA to test various transformations yielded no improvement. We therefore present the original untransformed model with robust standard errors. Age and distance lived from food vendors were negatively associated with vegetable intake, indicating that older and more isolated individuals consumed, on average, fewer vegetables than their younger and less isolated counterparts. By contrast, high caste and time spent watching television were positively associated with vegetable intake.

In a final step, we build a logistic regression model that assessed the associations between characteristics of the food environment and a high energy-adjusted refined grain and low energy-adjusted vegetable consumption (HRGLV) diet (Table 7.7). A total of 160 individuals (crude prevalence 21%, including 22% of women and 20% of men) were identified as HRGLV. Age and agriculture occupation were associated with lower odds of HRGLV diets, suggesting that being older and participating in agriculture were protective against this diet. By contrast, vehicle ownership was associated with increased odds of HRGLV diet.

7.4 Discussion and Conclusion

The study group consumed considerably more coarse cereals and less rice in comparison to national-level averages (NIN 2009) (Table A3.2, Appendix 3). Mean consumption of cereals, fruits, and total carbohydrates were greater than national-level averages and recommended dietary allowances (RDAs), as defined by the National Institute of Nutrition (NIN 2009). Consumption of pulses was higher than national averages, but lower than RDAs. Consumption of vegetables was very low, both compared to national-level averages and RDAs, which likely accounts for the lower-than-recommend intakes of iron, vitamin A, and vitamin C. Average sugar intake was higher than RDAs for men but lower than RDAs for women. Salt intake was approximately three times the RDA for both men and women (WHO 2013).

7.4.1 The Food Environment in Rural TN

7.4.1.1 Individual factors: age, gender, education, literacy, and migration

Older age was associated with reduced refined grain intake, which corresponded with qualitative data suggesting that food preferences of young people are shifting away from coarse cereals to favour “new” foods, including refined rice. Interestingly, this finding challenges those of Radhika et al. (2009), who determined that age was not associated with refined grain intake in a population in urban Chennai. It is possible that the nutrition transition is transpiring differently in rural areas, where shifting food preferences and subsequent dietary change is disproportionately occurring among younger people. Older age was also associated with reduced intake of vegetables, which corresponds with findings by Radhika and colleagues (2011) in an urban population in southern India. Older age was also associated with reduced risk of a high refined grain and low vegetable (HRGLV) diet, a unique finding that suggests that younger individuals are consuming a diet more conducive to individual-level double burden of malnutrition. This may reveal the potential for future increases in the double burden of malnutrition.

The highest quartile of refined grain consumption had a greater proportion of females than the lowest quartile, and female gender was associated with higher energy-adjusted refined grain intake in the linear regression model. After adjustment for energy intake, men consumed less refined grains and more milk products (Table A3.1, Appendix 3). Qualitative data suggest that refined grains (e.g. rice) are often considered “*unhealthy*”, whereas milk products were considered “*healthy*”. Taken together, these findings suggest that women are consuming fewer foods perceived as “*healthy*” and more foods perceived as “*unhealthy*” when compared to men. Such results raise questions about the potential effects of intra-household gender discrimination on food consumption. Recent research conducted by the India Development Survey and Coffey

(2017) suggests that "men eat first" in upwards of 50% of households in Uttar Pradesh, which may have severe nutrition implications for women in households with a limited food budget (Desai & Vanneman 2012; Coffey 2017). Furthermore, Coffey indicates that "the person who eats last very often gets less or lower quality food". While such data are unavailable for households in rural Tamil Nadu, research on children suggests that girls are often neglected in favour of boys, which results in less-healthy diets, poorer measures of nutrition, and female mortality (Behrman 1988; Barcellos et al. 2014). Intra-household dynamics and gender discrimination may therefore play a role in women's food consumption, which may account for higher levels of anemia, underweight, overweight, and nutrition-related noncommunicable diseases among women in rural regions of India (NNMB 2006).

Education (assessed as number of years of formal schooling) was positively associated with refined grain intake. Education may be a proxy for socioeconomic status (described further below), or it may directly impact consumption patterns due to increased nutritional awareness (Blaylock 1999). Seasonal labour migration was identified by participants in the qualitative study as having an impact on food preference, which corresponds with the findings of Bansal et al. (2010) that migrant factory workers in urban areas of India consumed more white bread and pasta products than their rural counterparts. However, we found no associations between migration and consumption of refined grains or vegetables after multivariable adjustment.

7.4.1.2 Socio-economic-cultural factors

Income and socioeconomic status have a substantial impact on food choices and consumption by influencing the relative affordability of foods (Drewnowski & Darmon 2005). At the national level in India, improved socioeconomic status has been linked with dietary diversity (Shetty 2002) and increased consumption of animal products, vegetables and fruits, and refined grain (Kumar & Dey 2007). Although the wealth index was not associated with energy-adjusted consumption of refined grain or vegetables, we found that caste, which is intricately linked with socioeconomic status, was associated with increased intake of both refined grain and vegetables. However, this relationship is may be complicated by dietary restrictions on different castes (for example, vegetarianism among high caste Brahmins) and different entitlements through the Public Distribution System (described below). While religion has been shown to influence food choice (Dindyal & Dindyal 2003), and the dietary restrictions of Hindu and Muslims are well known, we found no significant associations between religion and refined grain or vegetable consumption. This may be due to the limited number of Muslims included in the study, and therefore limited power to determine statistical differences between Muslim and Hindu individuals.

7.4.1.3 The Public Distribution System

The Public Distribution System (PDS), mandated by the National Food Security Act of 2013, is perceived to have an enormous impact on food availability and affordability in the research site (Little et al. 2016). The PDS is a large government scheme that distributes a number of commodities to households across India. These commodities consist of food grain (primarily refined wheat and rice), cooking oil, kerosene, and sugar (Mooij 1998). Food grains are purchased by the central government through the Food Corporation of India, which pays a government-mandated minimum support price. Following grain acquisition, it is often stored as buffer stock before distribution at below-market price through state-mandated Fair Price Shops (FPSs) (Jha et al. 2011). Such shops are pervasive in Tamil Nadu; indeed, there are currently over 30,900 shops throughout Tamil Nadu, and several within the research site (Tamil Nadu

Civil Supplies Corporation 2011). In 1997, in order to provide preferential benefits for the 'poorest of the poor', universal coverage of the PDS gave way to the targeted PDS, which categorizes families according to economic status and provides entitlements based on income, dependents, caste, household size, marital status, and land holdings, as well as special circumstances such as HIV+ status, homelessness, and disability (TNCSC 2011). State governments mandate prices in FPSs; in Tamil Nadu, eligible households are entitled to between 20 and 35 kg of free food grain (primarily rice) every month. Sugar, kerosene, cooking oil, and occasionally pulses are also provided for below-market prices.

The PDS is a troubled program. Supporters claim it is a targeted social welfare strategy that acts as an implicit income transfer and significantly reduces poverty (Drèze 2013) and severe under-nutrition (Radhakrishna & Subbarao 1998). Conversely, detractors claim the PDS is an inefficient use of resources (Kochar 2005), corrupt, prone to leakage (i.e. employees embezzling products) (Gulati and Saini 2015; Mooij 1998), and distributes low-quality goods (Balakrishnan & Ramaswami 1997). While participants in our study relied on the program for household food security, many complained about the quality of grain. Some researchers have noted that the PDS skews cereal consumption away from coarse cereals toward refined rice, with potential impacts on health outcomes due to the relative poor nutritional content of PDS grain (Khera 2011). Interestingly, we found that individuals in the lowest quartile of refined grain consumption had the highest PDS entitlements. This may indicate that individuals with the greatest entitlements are more likely to sell excess grain for profit as described in the qualitative findings. This practice has been documented in food rationing programs in other countries (USAID 2006), but never in India. Nevertheless, over the long term, the PDS improves availability of refined grain and other products that it promotes, which may be contributing to the increased intake of these foods in recent years. Thus, the PDS likely plays an active role in the nutrition shift and is a crucial component of the food environment in rural TN.

7.4.1.4 Agriculture

Agricultural patterns in India have shifted dramatically over the past decades in ways that closely match food consumption trends. As shown by Birthal et al. (2011), diversification of agriculture away from cereals has occurred in all states, but particularly in Tamil Nadu, where production of cereals (and especially coarse cereals) has declined by 43% from 1993 to 2008 (Saravanadurai & Kalaivani 2010). Pulse and oilseed production has similarly declined. Meanwhile, production of fruits and vegetables, as well as the amount of land devoted to livestock production, have increased drastically (Department of Agriculture Cooperation & Farmers Welfare 2016). Such changes are reflective of improvements in agricultural technologies and transport and market infrastructure that have made commercial food production viable in all but the most remote locations (Pingali 1997). Despite this, commercial agriculture was relatively rare in the research site, and most landowners still produced food for their own consumption. Importantly, participation in agriculture was significantly associated with reduced consumption of refined grain, likely due to individuals consuming millets and other nutritious self-produced foods. Agricultural livelihoods were not associated with vegetable intake, perhaps due to the rarity of vegetable production among subsistence landholders, as described in the qualitative interviews.

7.4.1.5 Geography and Rurality

Geography is a primary characteristic of the food environment, and has been shown to influence availability of food through access to different food vendors and markets (Health

Canada 2013). Previous studies have compared rural and urban diets in India, and found that urban populations tend to have greater dietary diversity and higher consumption of refined grains, fats, vegetables, and fruits (Singh et al. 1995; NNMB 2006). However, no studies known to the authors have examined dietary intake across a *gradient* of rurality. We found that, despite the uniform rural status of the study population as per the Census India definition, trends in the research site mirror those of the rural-urban divide, in that decreased rurality (i.e. lower rurality index and closer proximity to food vendors and markets) was associated with higher intake of refined grain. Improved access to food markets (kilometers to food market) was also associated with increased vegetable consumption. These results may be reflective of the relatively higher availability of both healthy (e.g. vegetables) and unhealthy (e.g. refined grains) foods in larger villages.

Rurality may be mediated by ownership of a vehicle, which reduces the opportunity costs of traveling to obtain food, thus improving the convenience of food from government shops, food markets, and food vendors. Interestingly, while vehicle ownership was not associated with intake of refined grain and vegetables individually, it was associated with greater odds of co-occurring high refined grain and low vegetable (HRGLV) intake. This association is difficult to explain, but may be due to the reduced constraints of accessing food markets and food vendors.

7.4.1.6 Cultural preferences

There is often a gap between how we expect individuals to behave based on food availability and affordability, and how they actually behave. In Atkin’s (2013) words, there is a “component of the food budget share that cannot be explained by the vector of prices or total food expenditure in a demand system”. This component can instead be explained by desirability, or food preferences. While the food culture of Tamil Nadu has yet to be fully elucidated in the literature, the cultural importance and entrenched traditions of food across India have been noted (e.g. Singh & Singh 2007). Certain phenomena have been recorded; for example, the impact of religion on diet (discussed above) and the conceptualization of food as a status symbol (Schoen 2013). Further, economists have noted that cereals (and in particular, coarse cereals) are perceived as 'inferior' goods (demand decreases when income rises), while processed foods, fruits, vegetables, and restaurant items are viewed as 'superior' goods (demand increases when income rises) (Pons 2011), which may expose the inherent desirability of such foods. In addition to being culturally embedded, desirability of food may be influenced by environmental processes such as food advertising and public health messaging.

In the qualitative interviews, participants mentioned the influence of television advertising and on food choice. Furthermore, some participants asserted that television was educational, which suggests that television-based public health messaging may also influence food choices. Following this, we assessed associations between ownership of a television and time spent watching television on refined grain and vegetable intake. We found that television ownership was positively associated with energy-adjusted refined grain intake. While television ownership may be a proxy for socioeconomic status, it is possible that advertising influenced individuals' choices by tilting preferences towards heavily advertised foods – namely, sugar-sweetened beverages, processed snack foods, and foods containing refined grains. Indeed, Vijayapushpam and colleagues (2014) conducted a comparative analysis of television food advertisements in India, and found that more than 50% of advertisements were for cake, pizza, and candy products, while only 33% were for vegetable or fruit-based products. Despite the relatively low coverage in advertising spaces, individuals in the highest quartile of vegetable intake were likely to spend more time watching television, and hours spent watching television was associated with energy-adjusted vegetable intake. Such findings may indicate the effectiveness of television-based nutritional messaging. These results contradict those of Vereecken et al. (2006) and Boynton-Jarrett et al. (2003), who found that television viewing was associated with decreased vegetable consumption among adolescents in a number of countries in North America and Europe. It is possible that this association differs between high-income and low and middle-income countries.

7.4.2 Palatability and preparation time

Palatability and preparation time may influence individuals' food choices. However, these are characteristics of foods themselves and not of individuals or their environment, so we did not assess their influence on food consumption patterns in quantitative models. Nevertheless, qualitative findings suggest that both of these factors were influential on food consumption the research site.

National trends in food patterns indicate a shift towards more palatable foods (i.e. foods that are more pleasing), which include meat, fish, sugar, salt, and vegetable fats (Kearney 2010; Shetty 2002). Furthermore, the relative palatability of convenience foods high in fats and sugars (Kessler [2009] calls these "hyper-palatable" foods) compared to traditional foods (e.g. coarse cereals) may promote their consumption, particularly in uneducated and under-resourced populations (Worsley 2002). The increased availability of such foods in rural regions, combined with the palatability of such foods, advertising campaigns aimed at young people (Vijayapushpam et al. 2014), and the tendency of older adults to favor foods consumed as a child (Birch 1999), may explain the difference in food consumption patterns across age groups.

Despite this, no research in India has focused on age-related food choices and the complexities of food preferences among young people. This represents an area of interest for future research.

Intra-household gender dynamics have already been discussed. However, gender roles (which are changing rapidly in urban India, and relatively slower in rural India) may also play a role in household food obtainment and consumption. In rural south India, women typically purchase and prepare meals for the household. However, women are increasingly entering the workforce outside the home (Shanthi 2006). Programs such as the Mahatma Gandhi National Rural Employment Guarantee Act (MGNREGA), which has in recent years become a program dominated by women participants, are contributing to this trend (Afridi et al. 2012). As such, there is an increased opportunity cost of women's time. When women's time is scarce, preparation time may influence food choice and consumption (Cawley 2004). Some women in the qualitative interviews communicated this, insisting, "rice is easier to cook". Unfortunately, similar to other regions around the world (Jabs & Devine 2006), healthy (and traditional) foods take considerably more time to prepare than unhealthy ones, likely contributing to their decline in recent years, and possibly contributing to increased refined grain consumption in the research site.

7.4.3 Limitations

This study has several limitations. Food environments and their effects on food choice and consumption vary between populations (e.g. Moore et al. 2008), so findings are likely not representative of state or national populations in India. As with all cross-sectional studies, sampling methods preclude our ability to determine causation; thus, all associations must not be misconstrued as causative.

Although we employed validated methods to collect most data, there were some notable exceptions and limitations. Our asset-based wealth index was modified from the validated one used by the NFHS, and was not validated against other measures of wealth in our population. Our rurality index was adapted from one developed for health research in the US, but was not previously validated for use in India (Weinert & Boik, 1995). Finally and most importantly, dietary intake is "notoriously difficult to measure" (Byers 2001). While our food frequency questionnaire was previously validated for use in urban Tamil Nadu (Sudha et al. 2006), its applicability to rural regions may be limited, particularly in light of findings by Martín–Moreno et al. (1993) that validity of FFQs is reduced among populations with low literacy and homogenous diets. In addition, FFQs may be subject to biases such as social desirability or social approval. Strong beliefs about associations between food habits and health may exacerbate these biases (Messer 1997). FFQs also tend to over-estimate food intake, so absolute values presented in this article should be interpreted with caution (Sudha et al. 2006).

7.4.4 Conclusion

The double burden of malnutrition is a serious public health concern in rural India, and food environments are likely contributing to the co-occurrence of under- and over-nutrition at the household and individual levels. High refined grain consumption and low vegetable consumption have received attention recently for their contributions to obesity, NCDs, and micro-nutrient deficiencies. With this in mind, we explored the food environment and its effect on food consumption patterns in a rural region of Tamil Nadu. Using a concurrent mixed methods study design, we assessed perceived environmental characteristics that influence drivers of food choice and consumption (availability, affordability, convenience, and desirability of foods).

In qualitative interviews, participants identified a number of characteristics that comprise the local food environment, including individual factors (e.g. age, sex, education, and migration), socio-economic-cultural factors (e.g. religion, caste, and wealth), ration entitlements through the Public Distribution System, geography (e.g. rurality), participation in agriculture, type of agriculture, and exposure to media. We assessed associations between these environmental characteristics and consumption of refined grains and vegetables. In fully-adjusted models, we found that female gender, high caste, more education, and television ownership were positively associated with energy-adjusted refined grain intake. Higher rurality, participation in agriculture, and age were negatively associated with energy-adjusted refined grain intake. Female gender, higher caste, and time spent watching television were positively associated with energy-adjusted vegetable intake, while age and increased distance to the food market were negatively associated with energy-adjusted vegetable intake. Furthermore, vehicle ownership was associated with increased odds of a high refined grain, low-vegetable diet, while age and participation in agriculture were associated with decreased odds of a high refined grain, low-vegetable diet.

These findings expose several interesting phenomena that require further research into the effects of the food environment on food choice and consumption in rural India. There is some evidence to suggest that public health messaging, and in particular television-based nutrition messaging, may have a positive influence on consumption of vegetables. Considering the high occurrence of television ownership in rural regions of Tamil Nadu, television messaging may have significant potential to positively or negatively influence dietary choice and consumption. In designing public health policy and programming to mitigate the consequences of the double burden of malnutrition, it may be prudent to focus on improving availability, affordability, desirability, and convenience of healthy foods by addressing agricultural patterns, socio-economic disparities, and improving access to healthy food markets for rural and marginalized populations.

REFERENCES

Afridi, F., Mukhopadhyay, A., & Sahoo, S. (2012). Female labour force participation and child education in India: the effect of the national rural employment guarantee scheme. IZA Discussion Paper No. 6593. Available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2085180. Accessed 8 March 2017.

Atkin, D. (2013). Trade, tastes, and nutrition in India. *The American Economic Review*, *103*(5), 1629-1663.

Balakrishnan, P., & Ramaswami, B. (1997). Quality of Public Distribution System: Why it matters. *Economic & Political Weekly, 32*(4), 162-165.

Bansal, D., Satija, A., Khandpur, N., Bowen, L., Kinra, S., et al. (2010). Effects of migration on food consumption patterns in a sample of Indian factory workers and their families. *Public Health Nutrition*, *13*(12), 1982-1989.

Barcellos, S. H., Carvalho, L. S., & Lleras-Muney, A. (2014). Child gender and parental investments in India: are boys and girls treated differently? *American Economic Journal: Applied Economics*, *6*(1), 157-189.

Behrman, J. R. (1988). Intrahousehold allocation of nutrients in rural India: Are boys favored? Do parents exhibit inequality aversion? *Oxford Economic Papers*, *40*(1), 32-54.

Birch, L. L. (1999). Development of food preferences. *Annual Review of Nutrition*, *19*(1), 41-62.

Birthal, P. S., Singh, H., & Kumar, S. (2011). Agriculture, economic growth and regional disparities in India. *Journal of International Development*, *23*(1), 119-131.

Blaylock, J., Smallwood, D., Kassel, K., Variyam, J., & Aldrich, L. (1999). Economics, food choices, and nutrition. *Food Policy*, *24*(2), 269-286.

Bose, K., Biswas, S., Bisai, S., Ganguli, S., Khatun, A., Mukhopadhyay, A., & Bhadra, M. (2007). Stunting, underweight and wasting among Integrated Child Development Services (ICDS) scheme children aged 3–5 years of Chapra, Nadia District, West Bengal, India. *Maternal & Child Nutrition*, *3*(3), 216-221.

Boynton-Jarrett, R., Thomas, T. N., Peterson, K. E., Wiecha, J., Sobol, A. M., & Gortmaker, S. L. (2003). Impact of television viewing patterns on fruit and vegetable consumption among adolescents. *Pediatrics*, *112*(6), 1321-1326.

Byers, T. (2001). Food frequency dietary assessment: how bad is good enough? *American Journal of Epidemiology*, *154*(12), 1087-1088.

Campbell, K. J., Crawford , D. A., Ball, K. (2006). Family food environment and dietary behaviors likely to promote fatness in 5-6 year-old children. *International Journal of Obesity, 30*, 1272-1280.

Campbell, K. J., Crawford, D. A., Salmon, J., Carver, A., Garnett, S. P., & Baur, L. A. (2007). Associations between the home food environment and obesity-promoting eating behaviors in adolescence. *Obesity*, *15*(3), 719-730.

Cawley, J. (2004). An economic framework for understanding physical activity and eating behaviors. *American Journal of Preventive Medicine*, *27*(3), 117-125.

Clark, S. E., Hawkes, C., Murphy, S. M., Hansen-Kuhn, K. A., & Wallinga, D. (2012). Exporting obesity: US farm and trade policy and the transformation of the Mexican consumer food environment. *International Journal of Occupational and Environmental Health*, *18*(1), 53-64.

Coffey, D. (2017). When women eat last. *The Hindu, Jan. 7th 2017 edition.* Available at: http://www.thehindu.com/opinion/op-ed/When-women-eat-last/article16978948.ece?homepage=true. Accessed 16 March 2017.

Cohen, M. J. (2007). Food Security: Vulnerability despite Abundance. Working Paper Series, International Peace Academy. Available at: ifpri.org/pubs/books/ar2007/ar07external.pdf . Accessed 9 Jun 2016:

Dauchet, L., Amouyel, P., Hercberg, S., & Dallongeville, J. (2006). Fruit and vegetable consumption and risk of coronary heart disease: a meta-analysis of cohort studies. *The Journal of Nutrition*, *136*(10), 2588-2593.

Deaton, A. & Dreze, J. (2009) Food and nutrition in India: Facts and interpretations. *Economic and Political Weekly, 44* (7): 42-65.

Department of Agriculture Cooperation and Farmers Welfare. (2016). All India Crop Situation. Available at: http://agricoop.nic.in/all-india-crop-situation. Accessed 8 March 2017.

Desai, S., & Vanneman, R. (2012). India Human Development Survey II (IHDS-II). [TSV dataset]. Available at: http://ihds.info/. Acceessed 16 March 2017.

Dindyal, S., & Dindyal, S. (2003). How personal factors, including culture and ethnicity, affect the choices and selection of food we make. *Internet Journal of Third World Medicine*, *1*(2), 27-33.

Drewnowski, A., & Darmon, N. (2005). The economics of obesity: dietary energy density and energy cost. *The American Journal of Clinical Nutrition*, *82*(1), 265S-273S.

Drewnowski, A., & Popkin, B. M. (1997). The nutrition transition: new trends in the global diet. *Nutrition Reviews*, *55*(2), 31-43.

Drèze, J. (2013). *Rural poverty and the public distribution system*. Doctoral dissertation, Department of Economics, Delhi School of Economics.

Ebrahim, S., Kinra, S., Bowen, L., Andersen, E., Ben-Shlomo, Y., et al. (2010). The effect of rural-to-urban migration on obesity and diabetes in India: a cross-sectional study. *PLoS Medicine*, *7*(4), e1000268.

Garrett, J. L., & Ruel, M. T. (2003). Stunted child-overweight mother pairs: An emerging policy concern. *Washington, DC: International Food Policy Research Institute (IFPRI)*, 13-8.

Gillespie, S., & Haddad, L. (2003). *The double burden of malnutrition in Asia: causes, consequences, and solutions*. Delhi: Sage Publications.

Guha-Khasnobis, B., & James, K. S. (2010). *Urbanization and the South Asian enigma: A case study of India* (No. 2010, 37). Working paper//World Institute for Development Economics Research.

Gulati, A., & Saini, S. (2015). Leakages from Public Distribution System (PDS) and the way forward. Working Paper 294, International Council for Research on International Economics. Available at: http://icrier.org/pdf/Working_Paper_294.pdf. Accessed 8 March 2017.

Gupta, R., Joshi, P., Mohan, V., Reddy, K. S., & Yusuf, S. (2008). Epidemiology and causation of coronary heart disease and stroke in India. *Heart*, *94*(1), 16-26.

He, K., Hu, F. B., Colditz, G. A., Manson, J. E., Willett, W. C., & Liu, S. (2004). Changes in intake of fruits and vegetables in relation to risk of obesity and weight gain among middle-aged women. *International Journal of Obesity*, *28*(12), 1569-1574.

Health Canada. (2013). Measuring the food environment in Canada. Available at: http://www.foodsecuritynews.com/resource-documents/MeasureFoodEnvironm_EN.pdf. Accessed 8 March 2017.

Herforth, A., & Ahmed, S. (2015). The food environment, its effects on dietary consumption, and potential for measurement within agriculture-nutrition interventions. *Food Security*, *7*(3), 505-520.

Institute for Health Metrics and Evaluation (IHME) (2013). The global burden of disease: Generating evidence, guiding policy. Available at: http://www.healthdata.org/sites/default/files/files/policy_report/2013/GBD_GeneratingEvidence/IHME_GBD_GeneratingEvidence_FullReport.pdf. Accessed 1 Jan 2017.

International Institute for Population Sciences (IIPS). (2007). National Family Health Survey (NFHS-3). Mumbai, India: IIPS. Available at: http://rchiips.org/nfhs/NFHS-3%20Data/VOL-1/India_volume_I_corrected_17oct08.pdf. Accessed 16 Feb 2017.

International Institute for Population Sciences (IIPS). (2008). District Level Household and Facility Survey 2007-2008. Available at: http://rchiips.org/pdf/INDIA_REPORT_DLHS-3.pdf. Accessed 29 March 2017.

Jabs, J., & Devine, C. M. (2006). Time scarcity and food choices: an overview. *Appetite*, *47*(2), 196-204.

Jha, R., Gaiha, R., & Sharma, A. (2009). Calorie and micronutrient deprivation and poverty nutrition traps in rural India. *World Development*, *37*(5), 982-991.

Jha, R., Bhattacharyya, S., & Gaiha, R. (2011). Social safety nets and nutrient deprivation: An analysis of the National Rural Employment Guarantee Program and the Public Distribution System in India. *Journal of Asian Economics*, *22*(2), 189-201.

Jones, A. D., Hayter, A. K., Baker, C. P., Prabhakaran, P., Gupta, V., et al. (2016). The co-occurrence of anemia and cardiometabolic disease risk demonstrates sex-specific sociodemographic patterning in an urbanizing rural region of southern India. *European Journal of Clinical Nutrition*, *70*(3), 364-372.

Kearney, J. (2010). Food consumption trends and drivers. *Philosophical Transactions of the Royal Society: Biological Sciences*, *365*(1554), 2793-2807.

Kessler D. (2009). The end of overeating: Taking control of the insatiable American appetite. New York, NY: Rodale.

Khera, R. (2011). Revival of the public distribution system: evidence and explanations. *Economic and Political Weekly*, *46*(44-45), 36-50.

Kochar, A. (2005). Can targeted food programs improve nutrition? An empirical analysis of India's public distribution system. *Economic Development and Cultural Change*, *54*(1), 203-235.

Kumar, P., & Dey, M. M. (2007). Long-term changes in Indian food basket and nutrition. *Economic and Political Weekly*, 3567-3572.

Little, M., Humphries, S., Patel, K., & Dewey, C. (2016). Decoding the type 2 diabetes epidemic in rural India. *Medical Anthropology,* 1-15.

Liu, S., Willett, W. C., Manson, J. E., Hu, F. B., Rosner, B., & Colditz, G. (2003). Relation between changes in intakes of dietary fiber and grain products and changes in weight and development of obesity among middle-aged women. *The American Journal of Clinical Nutrition*, *78*(5), 920-927.

Martín-Moreno, J. M., Boyle, P., Gorgojo, L., Maisonneuve, P., Fernandez-rodriguez, J. C., Salvini, S., & Willett, W. C. (1993). Development and validation of a food frequency questionnaire in Spain. *International Journal of Epidemiology*, *22*(3), 512-519.

Messer, E. (1997). Intra-household allocation of food and health care: current findings and understandings—introduction. *Social Science & Medicine*, *44*(11), 1675-1684.

Misra, A., Singhal, N., Sivakumar, B., Bhagat, N., Jaiswal, A., & Khurana, L. (2011). Nutrition transition in India: Secular trends in dietary intake and their relationship to diet‐related non‐communicable diseases. *Journal of Diabetes*, *3*(4), 278-292.

Mohan, V., Radhika, G., Vijayalakshmi, P., & Sudha, V. (2010). Can the diabetes/cardiovascular disease epidemic in India be explained, at least in part, by excess refined grain (rice) intake? *The Indian Journal of Medical Research*, *131*, 369-72.

Mooij, J. (1998). The political economy of the Public Distribution System in India. *Journal of Peasant Studies 25*(2):1-22.

Moore, L. V., Roux, A. V. D., Nettleton, J. A., & Jacobs, D. R. (2008). Associations of the local food environment with diet quality—a comparison of assessments based on surveys and geographic information systems the multi-ethnic study of atherosclerosis. *American Journal of Epidemiology*, *167*(8), 917-924.

National Institute of Nutrition. (2009). Nutrient requirements and recommended dietary allowances for Indians: A report of the expert group of the Indian Council of Medical Research. Available at: http://icmr.nic.in/final/rda-2010.pdf. Accessed 5 March 2017.

National Institute of Nutrition. (2011). Dietary guidelines for Indians: A manual. Available at: http://ninindia.org/dietaryguidelinesforninwebsite.pdf. Accessed 5 March 2017.

National Nutrition Monitoring Bureau (NNMB). (2006). Diet and nutritional status of populations and prevalence of hypertension among adults in rural areas. Available at: http://nnmbindia.org/nnmbreport06nov20.pdf. Accessed 8 March 2017.

Nicholas, J., Wood, L., Harper, C., & Nelson, M. (2013). The impact of the food-based and nutrient-based standards on lunchtime food and drink provision and consumption in secondary schools in England. *Public Health Nutrition*, *16*(06), 1052-1065.

Pathak, P., Kapil, U., Kapoor, S. K., Saxena, R., Kumar, A., et al. (2004). Prevalence of multiple micronutrient deficiencies amongst pregnant women in a rural area of Haryana. *Indian Journal of Pediatrics*, *71*(11), 1007-1014.

Pingali, P. L. (1997). From subsistence to commercial production systems: The transformation of Asian agriculture. *American Journal of Agricultural Economics*, *79*(2), 628-634.

Pires, A.M., & Rodrigues, I. M. (2007). Multiple linear regression with some correlated errors: classical and robust methods. *Statistics in Medicine*, *26*, 2901-18.

Pons, N. (2011). Food and prices in India: Impact of rising food prices on welfare. *Session*, *7*, 15-17.

Pradeepa, R., Anjana, R. M., Joshi, S. R., Bhansali, A., Deepa, M., et al. (2015). Prevalence of generalized & abdominal obesity in urban & rural India-the ICMR-INDIAB Study (Phase-I)[ICMR-INDIAB-3]. *Indian Journal of Medical Research*, *142*(2), 139.

Radhakrishna, R., & Subbarao, K. (1998). Public Distribution System: Impact on Poor and Options for Reform. *Economic & Political Weekly*, *33*(35), 2285-2290.

Radhika, G., Sathya, R. M., Ganesan, A., Saroja, R., Vijayalakshmi, P., Sudha, V., & Mohan, V. (2011). Dietary profile of urban adult population in South India in the context of chronic disease epidemiology (CURES–68). *Public Health Nutrition*, *14*(04), 591-598.

Radhika, G., Van Dam, R. M., Sudha, V., Ganesan, A., & Mohan, V. (2009). Refined grain consumption and the metabolic syndrome in urban Asian Indians (Chennai Urban Rural Epidemiology Study 57). *Metabolism*, *58*(5), 675-681.

Rao, C., Kamath, V., Shetty, A., & Kamath, A. (2010). A study on the prevalence of type 2 diabetes in coastal Karnataka. *International Journal of Diabetes in Developing Countries*, *30*(2), 80.

Saravanadurai, A., & Kalaivanim, N, (2010). Growth actions of selected cereal crops in Tamilnadu state. *International Journal of Applied Biology and Pharmaceutical Technology, 1*(3), 778-785.

Schoen, J. (2013). New global middle class hungers for good ol' US fast food. Report for CNBC. Available at: http://www.cnbc.com/id/100950287. Accessed 8 March 2017.

Sen, S., Chakraborty, R., De, B., & Devanna, N. (2015). Trends in diabetes epidemiology in Indian population in spite of regional disparities: a systemic review. *International Journal of Diabetes in Developing Countries*, *35*(3), 264-279.

Shanthi, K. (2006). *Female labour migration in India: Insights from NSSO data* (Vol. 4). Madras School of Economics. Available at: https://ideas.repec.org/p/mad/wpaper/2006-04.html. Accessed 29 March 2017.

Shetty, P. S. (2002). Nutrition transition in India. *Public Health Nutrition*, *5*(1a), 175-182.

Singh, A., & Singh, R. K. (2007). Cultural significance and diversities of ethnic foods of Northeast India. *Indian Journal of Traditional Knowledge, 61*(1), 79-94.

Singh, R. B., Ghosh, S., Niaz, A. M., Gupta, S., Bishnoi, I., et al. (1995). Epidemiologic study of diet and coronary risk factors in relation to central obesity and insulin levels in rural and urban populations of north India. *International Journal of Cardiology*, *47*(3), 245-255.

Singh, R. B., Niaz, M. A., Rastogi, S. S., Bajaj, S., Gaoli, Z., & Shoumin, Z. (1998). Current zinc intake and risk of diabetes and coronary artery disease and factors associated with insulin resistance in rural and urban populations of North India. *Journal of the American College of Nutrition*, *17*(6), 564-570.

Stein, A. J., Nestel, P., Meenakshi, J. V., Qaim, M., Sachdev, H. P. S., & Bhutta, Z. A. (2007). Plant breeding to control zinc deficiency in India: how cost-effective is biofortification? *Public Health Nutrition*, *10*(05), 492-501.

Sudha, V., Radhika, G., Sathya, R. M., Ganesan, A., & Mohan, V. (2006). Reproducibility and validity of an interviewer-administered semi-quantitative food frequency questionnaire to assess dietary intake of urban adults in southern India. *International Journal of Food Sciences and Nutrition*, *57*(7-8), 481-493.

Swinburn, B., Dominick, C., & Vandevijvere, S. (2014). *Benchmarking Food Environments: Experts' Assessments of Policy Gaps and Priorities for the New Zealand Government*. Available at: https://www.fmhs.auckland.ac.nz/assets/fmhs/soph/globalhealth/informas/docs/Full%20Food-EPI%20report1.pdf. Accessed 29 March 2017.

Tamil Nadu Civil Supplies Corporation (TNCSC). (2011). Public Distribution System. Available at: http://www.tncsc.tn.gov.in/PDS.html. Accessed 8 March 2017.

Toteja, G. S., Singh, P., Dhillon, B. S., & Saxena, B. N. (2004). Iodine deficiency disorders in 15 districts of India. *Indian journal of pediatrics*, *71*(1), 25-28.

Upadhyay RP (2012). An overview of the burden of non-communicable diseases in India. *Iranian Journal of Public Health*, 41(3):1-8.

United States Agency of International Development (USAID). (2006). The cost of the food ration basket: A tool for PDS monitoring and evaluation. Available at: http://pdf.usaid.gov/pdf_docs/Pnadg723.pdf. Accessed 9 March 2017.

Vereecken, C. A., Todd, J., Roberts, C., Mulvihill, C., & Maes, L. (2006). Television viewing behaviour and associations with food habits in different countries. *Public health nutrition*, *9*(2), 244.

Vijayakumar G, Arun R, Kutty VR (2009). High prevalence of type 2 diabetes mellitus and other metabolic disorders in rural central Kerala. *Journal of the Association of Physicians India*, 57:563-7.

Vijayapushpam, T., Maheshwar, M., & Rao, D. R. (2014). A comparative analysis of television food advertisements aimed at adults and children in India. *Inernationalt Journal Innovative Research in Science and Engineering*, *2*, 476-83.

Walker, R. E., Keane, C. R., Burke, J. G. (2010). Disparities and access to healthy food in the United States: A review of food deserts literature. *Health & Place,16*, 876-884.

Weinert, C., & Boik, R. (1995). MSU Rurality Index: Development and evaluation. *Research in Nursing and Health,18*, 453-464.

Willett W, Stampfer M. (1998). Implications of total energy intake for epidemiological analysis. In: Willett W, ed. Nutritional epidemiology. New York (NY): Oxford University Press.

World Health Organization. (2005). WHO STEPS surveillance manual: the WHO STEPwise approach to chronic disease risk factor surveillance. Available at: http://www.who.int/ncd_surveillance/en/steps_framework_dec03.pdf. Accessed 4 March 2017.

World Health Organization. (2009). Global prevalence of vitamin A deficiency in populations at risk 1995-2005: WHO global database on vitamin A deficiency. Geneva: World Health Organization.

World Health Organization. (2011). World Health Organization. Global Physical Activity Questionnaire (GPAQ) Analysis Guide. Available at: http://www.who.int/chp/steps/resources/GPAQ_Analysis_Guide.pdf. Accessed 10 November 2013.

World Health Organization. (2013). Global action plan for the prevention and control of NCDs 2013-2020. Available at: http://apps.who.int/iris/bitstream/10665/94384/1/9789241506236_eng.pdf?ua=1. Accessed 5 March 2017.

World Health Organization. (2015). Fact Sheet No. 394: Healthy diet. Available at: http://www.who.int/mediacentre/factsheets/fs394/en/. Accessed 8 March 2017.

Worsley, A. (2002). Nutrition knowledge and food consumption: can nutrition knowledge change food behaviour? *Asia Pacific Journal of Clinical Nutrition*, *11*(s3).

FIGURES

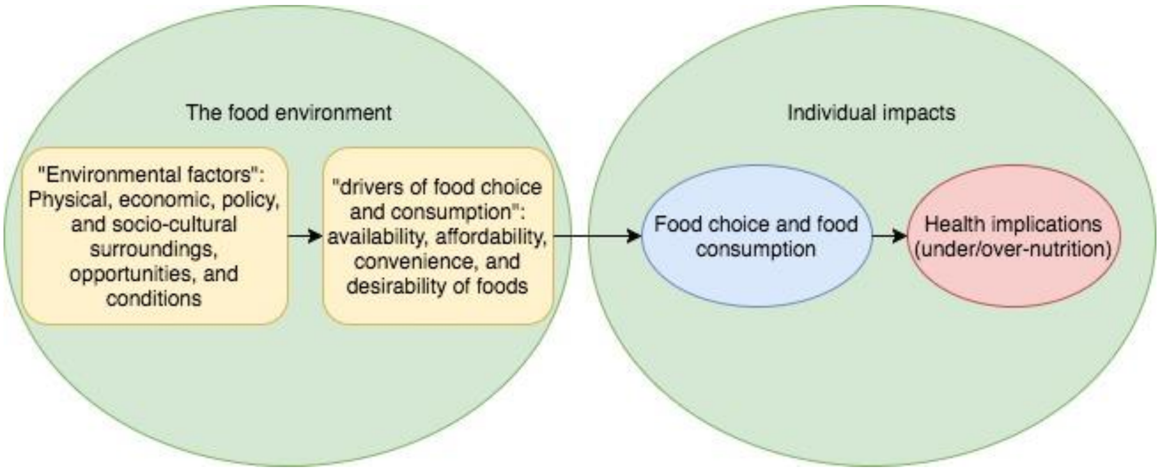

Figure 7.1: Framework for examining the food environment and its impacts on food choice/consumption and subsequent health implications

TABLES

Table 7.1: Consumption of food group and macro- and micronutrients, and comparison with recommended dietary allowances, in a sample of 753 adults (>19 years) in rural Tamil Nadu

	Intake mean ± SD			**Recommended dietary allowance**	
Foods (g/day unless otherwise specified)	**Women (n=411)**	**Men (n=341)**	**p-value***	**Women**	**Men**
Calories (kcal/day)	2219 ±629	2583 ±800	<0.001	2230 [a]	2730 [a]
Food groups					
Rice and rice products	151.2 ±74.6	159.8 ±88.4	0.15	NA	NA
Wheat and wheat products	21.3 ±22.8	20.9 ±24.0	0.79	NA	NA
Coarse cereals (e.g. millets, sorghum)	218.9 ±161.0	257.7 ±188.5	0.002	NA	NA
Total cereals	391.4	438.4		330[b]	450[b]
Pulses and pulse products	62.4 ±32.4	67.0 ±33.8	0.06	75[b]	90[b]
Milk and milk products	160.5 ±143.1	244.6 ±225.9	<0.001	300[b]	300[b]
Eggs, fish, and meat	7.4 ±13.6	10.6 ±19.8	0.008	NA	NA
Leafy vegetables	14.0 ±19.1	13.6 ±16.9	0.81	100[b]	100[b]
Other vegetables	24.3 ±22.7	24.2 ±21.9	0.95	100[b]	100[b]
Total vegetables	38.3 ±31.8	37.8 ±38.8	0.88	200[b]	200[b]
Roots and tubers	59.4 ±33.8	66.1 ±40.4	0.01	NA	NA
Fruit	140.4 ±126.9	147.7 ±135.6	0.45	100[b]	100[b]
Protein	57.2 ±16.6	65.8 ±19.8	<0.001	55[a]	60[a]
Carbohydrates	401.0 ±115.9	457.6 ±140.6	<0.001	400[b]	450[a]
Fats	44.2 ±18.6	50.7 ±21.8	<0.001	25[b]	30[b]
Dietary fibre	55.6 ±21.8	49.7 ±18.8	<0.001	40[c]	40[c]
Sugar, total	25.1 ±25.2	37.1 ±36.6	<0.001	30[b]	30[b]
Salt	14.1 ±7.32	15.6 ±8.02	0.61	<5[d]	<5[d]
Other nutrients					
Iron (mg/day)	13.4 ±6.6	14.2 ±6.7	0.11	21[a]	17[a]
Calcium (mg/day)	508.0 ±250.8	630.9 ±317.3	<0.001	600[a]	600[a]
Vitamin A (µg/day)					
Retinol	37.2 ±58.11	35.8 ±59.15	0.74	600[a]	600 [a]
β-carotene	2118.1 ±2279.6	2134.2 ±2354.0	0.92	4800 [a]	4800 [a]
Vitamin C (mg/day)	90.8 ±110.9	89.6 ±83.0	0.87	40 [a]	40 [a]
Thiamine (mg/day)	0.97 ±0.391	0.88 ±0.360	0.0011	1.1[a]	1.4 [a]

*p-value based on one way analysis of variance for differences in mean values between men and women

[a]RDA based on moderately physical active person (National Institute of Nutrition 2009)

[b]RDA based on "Balanced Diet for Adults – Moderate Activity" (National Institute of Nutrition 2011)

[c]RDA based on those made by Gopalan et al. (2004) for the Indian Council of Medical Research

[d]RDA based on WHO recommendations (WHO 2013)

Table 7.2: Characteristics of the food environment, their impact on drivers of food choice, and justification for their inclusion in statistical models

Characteristics (and variables assessed)	Justification for inclusion in analysis	Which drivers influenced?
Individual factors (age, gender, education, literacy, and migration)	• Age is associated with food preferences • Sex and gender may influence the within-household availability of foods • Education and literacy may influence an individual's knowledge on the relative healthfulness of different foods • Seasonal labour migration affects food availability and may result in adoption of food habits from destination.	Availability, desirability,
Socio-economic-cultural factors (household size, religion, caste, wealth)	• Household size (i.e. number of household members) affects distribution of resources • Wealth affects the food purchasing power and PDS entitlements • Caste affects entitlements through PDS • Caste and religion define some dietary restrictions (e.g. Brahmin caste Hindus will not eat meat, all Hindus will not eat beef, and Muslims will not eat pork)	Availability, affordability, convenience, desirability
PDS entitlements (kg/rice/month received for free by household)	• PDS entitlements were influenced by a variety of factors and ranged from 0 – 35 kg of free rice per month per household, along with differing quotas of subsidized oil, kerosene, sugar, and pulses • "Fair Price" PDS shops were more ubiquitous than private shops – several villages had no private shop, but did have a Fair Price shop	Availability, affordability, convenience
Geography (rurality, distance to convenience food vendors, distance to food market, ownership of vehicle)	• Rurality affected accessibility to food products, which may include beneficial foods (e.g. vegetables) at a food market, or detrimental foods (e.g. "fast" food, processed foods). • Vehicle ownership may mediate the effects of rurality by improving access to food vendors and markets	Availability
Agriculture (land owned, participation in agriculture, type of agriculture, livestock ownership)	• Land ownership influences the likelihood of an agricultural livelihood • Participation in agriculture, and type of agriculture, affects household availability of food, either by consuming food that is produced (subsistence agriculture), or by providing an income to increase food purchasing power (crops grown for local sale, commercial agriculture), or a combination of more than one of these types of agriculture. • Livestock ownership improves availability of meat and dairy products	Availability, affordability
Exposure to media (television ownership, time spent watching television)	• Advertising and popular culture influences the desirability of foods • Public health messages may educate individuals about the potential health effects of foods and encourage healthy eating.	Desirability

Abbreviations: PDS, Public Distribution System,

Table 7.3: Demographic and environmental characteristics of a sample of adults (>19 years) in rural south India by quartile of energy-adjusted refined grain intake (g/1000 kcal)

	Quartile of refined grain intake (adjusted for energy consumption)				
Characteristic	1 (low)	2	3	4 (high)	*p*-value*
n	188	188	188	188	
Mean refined grain intake (g/day)	68.3 ±45.0	142.3 ±43.2	182.6 ±56.6	227.4 ±75.4	-
Food environment characteristics					
Individual factors					
Women (%)	47.3	52.1	55.3	63.8	0.012[3]
Age (years)	53.2 ±14.3	47.7 ±14.7	44.2 ±14.0	43.5 ±13.9	<0.001[1,2,3,5]
Literate (%)	20.9	33.5	43.6	41.5	<0.001[2,3]
Education (maximum grade achieved)	1.66 ±3.3	2.84 ±4.0	4.02 ±4.6	3.66 ±4.6	<0.001[1,2,3,4]
Seasonal labour migration (%)	7.5	10.1	6.9	3.7	0.0044[4]
Socio-economic-cultural factors					
High caste (%) [Muslims excluded]	3.7	7.4	13.3	13.8	0.002[2,3]
Muslim religion (%) (Hindu as referent)	1.6	2.1	5.3	5.9	0.060
Wealth index	10.0 ±4.37	11.0 ±4.36	11.7 ±5.1	11.1 ±4.7	0.0057[2,3]
Household size (number of members)	4.7 ±2.62	4.3 ±1.93	4.4 ±1.90	4.3 ±1.94	0.31
Public Distribution System					
PDS entitlement (kg rice/household /month)	23.5 ±6.24	22.0 ±5.55	21.9 ±7.10	21.6 ±7.07	0.026[3]
Geography					
Rurality index	0.19 ±1.04	-0.49 ±1.32	-0.85 ±1.31	-0.91 ±1.3	<0.001[1,2,3,4,5]
Distance to convenience food vendors (street food or restaurants)	8.29 ±7.4	5.09 ±6.7	3.24 ±5.5	2.86 ±4.9	<0.001[1,2,3,4,5]
Distance to food market	9.01 ±7.6	5.89 ±6.7	4.23 ±5.5	3.82 ±4.9	<0.001[1,2,3,4,5]
Vehicle ownership (%)	22.9	24.5	33.2	30.9	0.077
Agriculture Patterns					
Land owned (acres)	1.52 ±1.74	1.48 ±1.74	1.29 ±2.2	0.82 ±1.4	<0.001[3,5]
Livestock ownership (%)	52.4	46.0	35.6	33.9	<0.001[2,3]
Agricultural livelihood (%)	77.3	57.4	47.6	37.2	<0.001[1,2,3,5]
Subsistence agriculture (%)	61.7	55.9	47.3	35.1	<0.001[2,3,5]
Crop production for local sale (%)	8.0	9.0	8.0	4.8	0.427
Commercial crop production (%)	13.3	10.6	9.6	7.4	0.304
Exposure to media					
Ownership of television (%)	82.9	87.2	93.1	92.0	0.006[2,3]
Time spent watching television (hours/day)	1.27 ±1.3	1.50 ±1.3	1.54 ±1.3	1.51 ±1.3	0.17

*P-values are for Pearson's chi square for proportions and one-way analyses of variance (ANOVA) for means
[1]Category 1 versus 2 different to p<0.05 with Sidak pairwise comparison
[2]Category 1 versus 3 different to p<0.05 with Sidak pairwise comparison
[3]Category 1 versus 4 different to p<0.05 with Sidak pairwise comparison
[4]Category 2 versus 3 different to p<0.05 with Sidak pairwise comparison
[5]Category 2 versus 4 different to p<0.05 with Sidak pairwise comparison
[6]Category 3 versus 4 different to p<0.05 with Sidak pairwise comparison

Table 7.4: Food environment characteristics associated with individual energy-adjusted refined grain intake (g/1000 kcal) based on multivariable linear regression in a sample of adults (>19 years) in rural south India

Variable	Coefficient	Robust Standard Error	*p*-value
Constant	75.37	6.71	<0.001
Age	-0.41	0.09	<0.001
Female gender	4.71	2.28	0.039
High caste (low/medium caste as referent)	11.52	0.94	<0.001
Rurality index	-5.16	0.94	<0.001
Agriculture as primary occupation	-8.16	2.41	0.001
Education (years of formal education)	0.72	0.29	0.012
Television ownership	7.56	3.78	0.046

Table 7.5: Demographic and environmental characteristics of a sample of adults (>19 years) in rural south India by quartile of adjusted vegetable intake)

	Quartile of vegetable intake (adjusted for energy consumption)				
Characteristic	1 (low)	2	3	4 (high)	*p*-value*
n	188	1889	188	188	-
Mean vegetable intake (g/day)	10.9 ±5.53	24.3 ±7.53	39.6 ± ±10.70	77.6 ±42.9	-
Food environment characteristics					
Individual factors					
Women (%)	50.5	52.7	56.9	58.5	0.38
Age	52.7±15.34	44.5 ±13.70	46.9 ±14.02	44.6 ±14.27	<0.001[1,2,3]
Literate (%)	23.4	38.5	39.9	37.7	<0.002[1,2,3]
Education (years of schooling)	2.1 ±3.62	3.1 ±4.21	3.4 ±4.47	3.6 ±4.52	<0.033[2,3]
Seasonal labour migrant (%)	6.9	12.2	14.4	8.0	0.06
Socio-economic-cultural factors					
High caste (%)	2.7	8.5	9.6	17.6	<0.001[35,6]
Muslim religion (%) (Hindu as referent)	3.7	5.3	3.2	2.7	0.56
Wealth index	10.4 ±4.70	11.1 ±4.56	11.1 ±4.78	11.2 ±4.64	0.393
Household size (number of members)	4.8 ±2.49	4.4 ±1.84	4.1 ±1.57	4.3 ±2.41	0.026[2]
Access to Public Distribution System					
PDS entitlement (kg rice/household /month)	22.8 ±6.09	21.8 ±7.25	22.6 ±6.70	21.9 ±5.52	0.36
Geography					
Rurality index	0.15 ±1.210	-0.71 ±1.329	-1.00 ±1.316	-0.50 ±1.15	<0.001[1,2,3,6]
Vehicle ownership (%)	23.4	31.9	29.4	26.6	0.288
Distance to convenience food vendors (street food or restaurants)	9.1 ±8.09	4.0 ±5.74	2.8 ±4.85	3.62 ±5.15	<0.001[1,2,3]
Distance to food market	9.8 ±8.28	4.8 ±5.74	3.7 ±4.80	4.7 ±5.0	<0.001[1,2,3]
Agriculture Patterns					
Land owned (acres)	1.5 ±2.00	1.23 ±1.78	1.02 ±1.56	1.34 ±1.81	0.040[2]
Livestock ownership (%)	53.5	40.4	33.5	40.6	0.001[1,2]
Agricultural livelihood (%)	70.7	50.3	45.7	48.4	<0.001[1,2,3]
Subsistence agriculture (%)	63.8	52.1	39.9	45.2	<0.001[2,3]
Crop production for local sale (%)	7.4	6.4	4.3	10.6	0.11
Commercial crop production (%)	12.2	12.7	7.4	7.4	0.15
Exposure to media					
Ownership of television (%)	81.4	87.0	92.6	94.1	<0.001[2,3]
Time spent watching television (hours/day)	1.2 ±1.33	1.5 ±1.34	1.6 ±1.31	1.54 ±1.2	0.045[2,3]

*P-values are for Pearson's chi square for proportions and one-way analyses of variance (ANOVA) for means

[1]Category 1 versus 2 different to p<0.05 with Sidak pairwise comparison

[2]Category 1 versus 3 different to p<0.05 with Sidak pairwise comparison

[3]Category 1 versus 4 different to p<0.05 with Sidak pairwise comparison

[4]Category 2 versus 3 different to p<0.05 with Sidak pairwise comparison

[5]Category 2 versus 4 different to p<0.05 with Sidak pairwise comparison

[6]Category 3 versus 4 different to p<0.05 with Sidak pairwise comparison

Table 7.6: Food environment characteristics associated with individual energy-adjusted vegetable intake (g/1000 kcal) in a sample of adults (>19 years) in rural south India based on multivariable linear regression

Variable	Coefficient	Robust Standard Error	*p*-value
Constant	29.96	3.28	<0.001
Age (years)	-0.16	0.06	0.006
Female sex (Y/N)	0.44	1.66	0.792
High caste (low/medium caste as referent)	6.82	2.84	0.017
Distance to food market (kilometers)	-0.29	0.13	0.026
Time spent watching television (h/day)	1.41	0.64	0.028

Table 7.7: Food environment characteristics associated with individual co-occurring high refined grain and low vegetable consumption in in a sample of adults (>19 years) in rural south India based on multivariable logistic regression

Food environment characteristic	OR (95% CI)
Age	0.99 (0.97, 1.00)[b]
Female sex	1.16 (0.80, 1.68)
Agriculture occupation	0.67 (0.47, 0.96)[b]
Vehicle ownership	1.53 (1.03, 2.26)[b]

[a]p<0.01; [b]p<0.05

CHAPTER EIGHT:

SUMMARY DISCUSSION, RECOMMENDATIONS, AND CONCLUSION

8.1 Overview of the thesis

The research presented in this thesis fulfilled a number of objectives in examining the issues of obesity, type 2 diabetes (hereafter diabetes), double burden of malnutrition, and food environments in rural Tamil Nadu. All research was conducted in four *panchayats* (townships) in the Krishnagiri District. Following a review of the current literature and available background information (Chapters 1-2), we assessed prevalence and risk factors associated with underweight, overweight, and obesity (Chapter 3). Subsequently, we examined prevalence and risk factors associated with impaired fasting glucose, impaired glucose tolerance, pre-diabetes, and diabetes (Chapter 4). Next, we presented and discussed the results of a qualitative study with 54 individuals with diagnosed diabetes to assess explanatory models and illness narratives, thus gaining an in-depth understanding of lived experiences with diabetes (Chapter 5). We then presented an examination of the individual-level double burden of malnutrition by examining co-morbid measures of under- and over-nutrition and risk factors associated with double burden pairings (Chapter 6). Finally, we traced upstream processes propagating the double burden of malnutrition using a food environment framework to identify a number of food environment characteristics and assess their association with food choice and consumption patterns (Chapter 7). This conclusion chapter aims to summarize key findings and reflect on the strengths and limitations of the research presented in this thesis. The chapter will end with a discussion of the implications for policy and practice before providing recommendations for future research.

8.1.1 Key findings

This thesis combined data from three separate but interconnected studies. First, we conducted 61 qualitative semi-structured household interviews, which were used to familiarize ourselves to local rhythms, lifestyles, and terminology, and to inform further studies. Data from these interviews were also assessed using a thematic content analysis to identify important characteristics of the rural food environment (presented in Chapter 7). We subsequently conducted qualitative semi-structured interviews and two gender-segregated focus groups with 54 individuals with diagnosed diabetes. We employed a thematic content analysis with the aim of identifying explanatory models and exploring illness narratives of individuals living with diabetes in rural south India (Chapter 5). Finally, we conduced a cross-sectional quantitative study with a random sample of 753 adults (>19 years). Two-stage sampling was employed, in which we randomly selected a portion of households and employed the WHO Kish method to randomly sample one individual from each selected household (WHO 2005). These data were analyzed using descriptive statistics and linear and logistic regression modeling techniques to identify prevalence and factors associated with: BMI, overweight, and obesity (Chapter 3); capillary blood glucose (CBG), pre-diabetes, and diabetes (Chapter 4); and finally, co-morbid anemia and overweight, and co-morbid anemia and diabetes (Chapter 6). In addition, these data were analyzed using linear and logistic regression modeling to assess associations between food environment characteristics and food consumption habits, including refined grain intake, vegetable intake, and a high refined grain, low vegetable diet (Chapter 7).

8.1.1.1 Prevalence of measures of underweight, overweight, pre-diabetes, diabetes, and individual-level double burden of malnutrition

The cross-sectional quantitative study contributed to a growing body of research demonstrating high rates of measures of under- and over-nutrition in a rural population in India.

Table 8.1 provides a summary of sex-segregated crude prevalence of a number of health outcomes. Age- and sex-standardized prevalence of underweight (BMI <18.5 kg/m^2) was 22.7%. Age- and sex-standardized prevalence of overweight (body mass index [BMI] ≥23 kg/m^2 and <25 kg/m^2) and obesity (BMI ≥25 kg/m^2) were 14.9% and 19.4%, respectively. Age- and sex-standardized prevalence of pre-diabetes and diabetes were 9.5% and 10.8%, respectively. Only 43.6% of individuals with diabetes were previously diagnosed.

Many of these prevalence estimates demonstrate poor health measures among the study population. Prevalence of underweight and anemia were lower in this population than national-level rural estimates but higher than state-level rural estimates (NNMB 2006). Prevalence of overweight and obesity was much higher than state-level rural estimates (NNMB 2006) but similar to other regional studies in South India (Gupta et al. 2008; Kaur et al. 2011). Hypertension was more prevalent than state-level estimates and regional population studies (Oommen et al. 2016; Venkatachalam et al. 2016). Overall, our results corroborate recent evidence that rural regions are experiencing high prevalence of obesity, diabetes, and hypertension. Such findings challenge the misconception that obesity and non-communicable diseases are primarily concerns of urban and affluent populations.

Individual-level co-morbid measures of under- and over-nutrition were also common, providing evidence for the existence of the double burden of malnutrition (Gillespie & Haddad 2003). We found that prevalence of co-occurring anemia and overweight or obesity was 22.6% among women and 12.0% among men (Chapter 6). Prevalence of co-morbid anemia and pre-diabetes was 5.3% among women and 2.9% among men, while prevalence of co-morbid anemia and diabetes was 5.6% among women and men. Such estimates are higher than those previously recorded in India (Jones et al. 2016), and pose particular concern for nutrition and health policy (discussed below).

8.1.1.2 Potential drivers of underweight, obesity, diabetes, and the double burden of malnutrition

We employed multivariable regression analyses to determine associations between potential risk factors and health outcomes.

8.1.1.2.1 Links between overweight, obesity, diabetes, and the double burden of malnutrition

Obesity and diabetes are inextricably linked, and so often occur in tandem that researchers often use the term “diabesity” (Astrup & Finer 2000). Our results add to the body of research suggesting that obesity is a major risk factor for diabetes. We found that higher body mass index and waist-to-hip ratio (standardized to mean=0 & SD=1) were associated with higher post-prandial capillary blood glucose (CBG), higher fasting CBG, and greater odds of diabetes [BMI OR 1.85; WHR OR 1.62] (Chapter 4). Interestingly, we found that both BMI and WHR were *independently* associated with these health outcomes in multivariable models, suggesting that both general obesity and abdominal obesity affect risk independently, and should be considered separately in research and clinical settings.

We found high prevalence of co-morbid anemia and overweight. Some research suggests that these conditions are pathophysiologically linked, inasmuch as micronutrient deficiencies may contribute to the development and exacerbation of noncommunicable diseases (NCDs) such as diabetes, and conversely that NCDs may reduce absorption of micronutrients and thus exacerbate micronutrient deficiency and associated disorders (Eckhardt et al. 2008). Other studies suggest that obesity and some NCDs further exacerbate oxidative stress, and may interact with dietary deficiencies to produce worse health outcomes (Furukawa et al. 2004; Thompson & Godin 1995). Similarly, evidence indicates that inflammation caused by obesity and diabetes reduces iron absorption, which may contribute to iron-deficiency anemia in individuals with these conditions (Aigner et al. 2014; Zimmermann et al. 2008). Such complex physiological pathways may partially explain the high rates of co-morbid anemia and overweight and co-morbid anemia and diabetes in the study population.

8.1.1.2.2 Socio-economic status and caste

Socio-economic status and caste are intricately linked in rural India. We used an asset-based wealth index to assess socio-economic status (SES), adapted from the National Family Health Survey developed by the International Institute for Population Science (IIPS 2007). Caste was analyzed as two fixed categories: low-caste (scheduled caste and scheduled tribe) and high-caste (Brahmin caste), with all other castes (Other Backward Castes, Most Backward Castes, and General Caste) combined in an amalgamated referent. SES was positively associated with BMI and greater odds of obesity class I [OR 1.07] and obesity class II [OR 1.09] (Chapter 3). High caste was associated with higher BMI and increased odds of overweight [OR 2.37], obesity class I [OR 3.54], and obesity class II [OR 4.62] (Chapter 3). In addition, high caste was associated with increased odds of co-morbid anemia and overweight [OR 3.17] (Chapter 6). It is likely that SES and caste act as 'distal' factors that alter more 'proximate' dietary and physical activity patterns in various ways, thus impacting health outcomes.

8.1.1.2.3 Gender

Gender dynamics in India, and their impact on health outcomes, have been an area of interest for researchers from multiple disciplines (Osmani & Sen 2003; Purkayastha et al. 2003). However, our results indicated very few differences in health outcomes between men and women. Women were at greater risk of obesity class II (BMI>30 kg/m^2), which corresponds with previous research from elsewhere in India (Agrawal & Ebrahim 2012; Misra et al. 2011). Women were almost twice as likely to suffer from anemia than men (Chapter 6), and were more likely to have co-morbid anemia and overweight [OR 2.31]. This aligns with previous research from India (de Benoist et al. 2008; Gupta et al. 2010; Jones et al. 2016). Such findings raise questions about the potential connections between gender discrimination and the double burden of malnutrition. Recent research suggests that men eat first, and consume higher-quality foods, in upwards of 50% of households in Uttar Pradesh (Coffey 2017; Desai & Vanneman 2012). While such data are unavailable for households in rural Tamil Nadu, research on children suggests that girls are often neglected in favour of boys, which results in poorer measures of nutrition and higher female mortality (Barcellos et al. 2014; Behrman 1988). Intra-household dynamics and gender inequality may therefore play a role in women's nutrition, and may exacerbate micronutrient deficiencies, obesity, diabetes, and the double burden of malnutrition among women.

8.1.1.2.4 The concept of rurality and its importance

A unique aspect of the research presented in this thesis was our exploration of the concept of 'rurality'. Rurality (and its inverse, urbanicity) has been studied in epidemiology research in high-income countries (e.g. Humphreys 1998; Weinert & Boik 1995), and to a lesser extent in low- and middle-income countries (Jones et al. 2016; Riha et al. 2014). We were the first research group, to our knowledge, to examine the concept of rurality along a rurality gradient within a context that was classified entirely as "rural" by Census India definitions. Our objective was to challenge the dichotomous rural/urban divide that is so often employed in epidemiology research, and particularly in India (e.g. Anjana et al. 2011; Mohan et al. 2008). To fulfill this objective, we adapted a rurality index that quantified rurality based on (1) distance from primary healthcare centre; and (2) population of home village. A greater rurality therefore indicated a combination of greater isolation and lower population density.

We found that rurality was a strong predictor of many health outcomes. In multivariable models, decreased rurality (i.e. decreased isolation and/or increased population density) was associated with higher BMI (Chapter 3), higher post-prandial blood glucose (Chapter 4), and increased odds of overweight [OR 1.43], obesity class I [OR 1.45], obesity class II [OR 2.44] (Chapter 3), pre-diabetes [OR 1.67], and diabetes [OR 1.32] (Chapter 4). In addition, decreased rurality was associated with lesser odds of underweight [OR 0.68] (Chapter 3). Finally, decreased rurality was associated with greater odds of co-morbid anemia and overweight [OR 1.45] and co-morbid anemia and diabetes [OR 1.33] (Chapter 6). Such results indicate that urban or semi-urban lifestyles, diets, and cultures may be linked with proximity to the market village and population density, thus increasing risk of obesity and diabetes. Interestingly, however, decreased rurality was also associated with greater odds of individual-level nutritional double burden, suggesting that despite experiencing relatively greater prevalence of obesity and diabetes, such lifestyles do not protect against micro-nutrient deficiency. Yet another important aspect of these findings is that it indicates that rural populations (and, for that matter, urban populations) should not be homogenized in future epidemiological research studies.

8.1.1.2.5 Physical activity

Low physical activity is a well-known risk factor for several health outcomes, particularly obesity and NCDs such as diabetes. Qualitative interviews revealed that physical activity was generally a function of occupation, and no interviewees admitted to exercising for pleasure, leisure, or health reasons (Chapter 5). In the cross-sectional study, we assessed physical activity using a Global Physical Activity Questionnaire (GPAQ), designed by the World Health Organization (WHO 2011). We then standardized all calculated values to hours per day of moderate physical activity. Increased physical activity was associated with decreased BMI, as well as reduced fasting CBG and post-prandial CBG. In addition, increased physical activity was associated with decreased odds of obesity class I [OR 0.94], obesity class II [OR 0.75] and diabetes [OR 0.81]. These data align with previous research and underscore the importance of physical activity in preventing and managing body weight and diabetes.

We also found that, independent of physical activity patterns, television ownership and time spent watching television were associated with BMI and obesity. Television ownership (which may be a proxy for SES and/or physical activity patterns) was associated with increased odds of being overweight in multi-variable regression models [OR 2.88]. Increased time spent watching television (h/day) was associated with higher BMI and increased odds of class I obesity in multi-variable models [OR 1.19]. Such findings align with studies on children in India, but ours was the first to determine such associations among adults (Kuriyan et al. 2007).

8.1.1.2.6 Dietary factors

Diet is known to play a role in the onset and management of obesity and diabetes. However, assessing dietary intake as a risk factor for health outcomes in studies in this research proved challenging. We employed a validated semi-quantitative food frequency questionnaire (FFQ), designed by the Madras Diabetes Research Foundation (MDRF), to collect dietary intake data (Sudha et al. 2006). Few dietary intake variables were associated with health outcomes. N-6 (also called omega-6) polyunsaturated fatty acid (PUFA) intake (scaled to g/1000 kcal) was positively associated with BMI and negatively associated with odds of underweight [OR 0.98] in a multivariable logistic regression model (Chapter 3). Animal fat intake was negatively associated with BMI in a multivariable linear regression model. Interestingly, and somewhat contradictory to the findings presented in Chapter 3, polyunsaturated fatty acid consumption was associated with lower post-prandial CBG and reduced odds of both pre-diabetes [OR 0.92] and diabetes [OR 0.94] in multivariable models (Chapter 4). However, considering the extensive limitations of the FFQ (discussed throughout this thesis, and in further detail below), it may be prudent to interpret these results with caution.

8.1.1.2.7 Tobacco use

Tobacco use was common in the research site. In total, 38.5% of participants used tobacco in some form at the time of the survey. Of these, 20.2% smoked cigarettes, while 19.5% chewed *paan*, a form of chewing tobacco. Tobacco use was associated with decreased BMI and lower odds of obesity class II [OR 0.15], likely due to its metabolic effects (Perkins et al. 1989) and its function an appetite suppressant (Jo et al. 2002). Tobacco use was also associated with higher fasting CBG and increased odds of diabetes [OR 2.82], which corresponds to cohort studies on both smoking and use of smokeless tobacco (Persson et al. 2000; Rimm et al. 1995; Willi et al. 2007).

8.1.1.2 Perceptions of diabetes (Chapter 5)

Qualitative inquiry can generate knowledge about lay perceptions and social experiences, which then offer insight into the health impacts of macro-level social, political, and economic processes. We sought to examine (1) explanatory models and (2) illness narratives to gain an understanding of the attitudes, perceptions, and experiences of 54 individuals living with diabetes in the study region.

Diabetes (known locally as the 'sugar disease') was perceived as a result of "*poor diet"* by almost half of participants. Specifically, participants implicated polished white rice (available locally through the Public Distribution System) and other *"new"* or "*urban"* foods like sugar-sweetened beverages, sweets, and chips. *"Tension",* a term for worry, anxiety, and grief, was also perceived to be a common cause of diabetes by 35% of participants. Finally, *"tradition", or "shared blood"*, which are local euphemisms for family history, was implicated in diabetes onset by one fifth of participants.

Illness narratives uncovered a number of interesting phenomena related to diabetes diagnosis and management. Importantly, diabetes diagnosis was often associated with "*tension"*, "*fear*", *"worry",* and a loss of "*control".* Diabetes management was associated with *"money problems"* and "*family problems".* Most participants managed diabetes through diet and medication. However, many only took medication when they felt ill. No participants exercised for pleasure, an important finding that underscores the lack of cultural acceptability of leisure activity. We found that patients lamented lost *"control"*, and many used noncompliance to recuperate lost autonomy. These qualitative findings are important to the design and implementation of culturally relevant public health and clinical initiatives. They are also useful for identifying underlying social, physical, and structural inequities that lead to increasing incidence of diabetes and act as barriers to health management.

8.1.1.3 The food environment (Chapter 7)

Qualitative interviews revealed a number of food environment characteristics that alter food choices and consumption by changing one or more of 'drivers': *availability, affordability, convenience,* and *desirability* of different foods. Participants claimed that demographic factors (age, sex, education, literacy, migration), socio-economic-cultural factors (household size, religion, caste, wealth), geography (rurality and distance to amenities), agricultural activities (type of agriculture, livestock ownership), exposure to media (through television), and food entitlements through the PDS all affected nutritional intake through one or more drivers of food choice and consumption.

In light of the interest in refined grain intake (e.g. Mohan et al. 2010; Radhika et al. 2009) and vegetable consumption (e.g. Gupta et al. 2008; He et al. 2004) and their effects on diabetes and the double burden of malnutrition, we assessed associations between numerous food environment characteristics and food consumption patterns. We found that, in multivariable models, female gender, higher caste, higher education, and television ownership were positively associated with energy-adjusted intake of refined grains. Meanwhile, older age, increased rurality, and agriculture as primary occupation were associated with decreased intake of refined grains. Furthermore, high caste and time spent watching television were positively associated with energy-adjusted intake of vegetables, while older age and increased distance to food market were negatively associated with energy-adjusted intake of vegetables.

Finally, we found that younger age (in years) [OR 0.99] and agriculture as primary occupation [OR 0.67] were associated with decreased odds of co-occurring high refined grain and low vegetable (HRGLV) consumption, while vehicle ownership [OR 1.53] was positively associated with a HRGLV diet. These results are particularly important to understand consumption habits that may increase the double burden of malnutrition.

8.2 Strengths of the research

We employed an interdisciplinary mixed-methods approach that took advantage of the complimentary benefits of qualitative and quantitative tools. We used qualitative methods as exploratory (e.g. Chapters 5 and 7) and explanatory (Chapter 7) devices, both to inform and explain quantitative tools and findings and thus gaining a level of understanding, complexity, nuance, and rigour that would not otherwise have been possible. Previous work on obesity, diabetes, the double burden of malnutrition, and food environments draw heavily from the disciplines of epidemiology, geography, nutrition, economics, sociology, and development studies. By immersing ourselves deeply in the research topics through a multitude of theoretical and methodological lenses, we enriched the research presented in this thesis.

Our quantitative cross-sectional study (presented in Chapters 3, 4, 6, and 7) was rigorous and employed validated measurement tools whenever possible. Immersion in the research site was accomplished by living in the community on two different occasions for a total of 13 months. We also used qualitative data to inform quantitative research tools, thereby improving their local relevance and cultural sensitivity. Systematic random sampling, training of research assistants, and consistent field practices ensured data were collected in ways that minimized potential biases. Our response rate was very high due to face-to-face recruitment. I was present for all interviews, questionnaires, and collection of health measures, and I entered or transcribed all data at the end of each day. These practices ensured data errors were corrected immediately and drift in data collection was minimized.

Our data analysis methods were similarly rigorous. With each participant, we collected information on numerous health outcomes, biometric data, and potential exposure variables, leading to a robust data set and permitting us to account for intervening and confounding variables. As mentioned in Chapter 4, while other studies have attempted to correlate risk factors with similar health outcomes (e.g. obesity, diabetes, and double burden of malnutrition) in India, most have focused on urban regions (e.g. Ajay et al. 2008; Radhika et al. 2011) or failed to account for multiple variables and confounders in complex multivariable statistical models (e.g. Agrawal et al. 2004; Kokiwar et al. 2007). Wherever possible, we included multi-level or continuous variables to limit loss of information and power (Hamilton & Filardo 2006; Royston et al. 2006; Taylor & Yu 2002). Our analysis in Chapter 7 was particularly unique and important, as it is the first study to examine drivers of food choice and consumption in India using a mixed-methods food environment framework.

8.3 Limitations of approach

Qualitative sampling (described in Chapters 5 and 7) was conducted using convenience and snowball sampling, so summary information (e.g. all percentages) from these studies lacks external validity. Cross-sectional sampling for the quantitative study (described in Chapters 2, 3, 4, 6, and 7) was conducted using systematic random sampling and a cross-sectional study design; thus we cannot establish a temporal sequence or direction of causation. While we attempted to alleviate these concerns in certain analyses (e.g. by excluding individuals with diagnosed diabetes in Chapter 4), it is certainly possible that reverse causation introduced bias. This may be of particular concern in Chapters 3 and 6, in which overweight or obesity (Chapter 3) and individual-level nutritional double burden (Chapter 6) may influence an individual's behavioural and dietary patterns. Behavioural change due to poor health may bias correlations toward the null, so associations presented in this thesis may in fact be stronger than calculated (Fewell et al. 2007).

Several local and contextual characteristics should be taken into consideration when making inferences beyond the study and source populations in the studies presented. Due to disparities in state, *taluk*, *panchayat*, and village governance, there are variations in the availability and quality of public services and entitlements for rural households in India. In addition to political variation, rural India is diverse in regards to many agricultural, economic, climatic, and socio-cultural factors. As such, the applicability of our findings to other regions in India may be limited. The area where these studies were conducted had a higher proportion of Scheduled Castes and Schedule Tribes (low caste) individuals and lower literacy levels compared to district and state-level averages (Karthikeyan et al. 2012).

As described in Chapters 3, 4, 6, and 7, there are several limitations of the food frequency questionnaire that necessitate cautious interpretation of dietary patterns and associations. While our FFQ was previously validated for use in urban Tamil Nadu (Sudha et al. 2006), its applicability to rural regions may be limited considering validity of FFQs is reduced among populations with low literacy (Martín-Moreno et al. 1993). FFQs may be subject to social desirability and social approval biases. Finally, FFQs are known to over-estimate food intake in many settings (Sudha et al. 2006).

We employed validated methods wherever possible, however there were some notable exceptions and limitations to data collection methods. Our asset-based wealth index (Chapters 3, 4, 6, & 7) was modified from a validated version used by the National Family and Health Survey, and our version was not validated against other measures of wealth (IIPS 2007). We employed a rurality index (Chapters 3, 4, 6, & 7) adapted from one developed for health research in the US, but was not previously validated for use in India (Weinert & Boik 1995). Due to limited access to laboratories and transportation constraints, we used capillary blood glucose (CBG) to assess impaired fasting glucose, impaired glucose tolerance, and diabetes (Chapters 4 & 6). CBG is known to have a wider coefficient of variation than venous plasma blood glucose (Anjana et al. 2011). However, there is good correlation between CBG and venous plasma estimations (Priya et al. 2011), and the World Health Organization endorses the use of CBG in low-resource settings (WHO 2006).

Finally, a severe limitation of the overall research approach was the unfortunate dearth of knowledge translation (KT) and mobilization (KM) activities resulting from our research, and the RESMISA project in general. While several publications will share findings with the academic community, there were few opportunities to translate, discuss, and mobilize research findings with policymakers, partner NGOs, community members, and study participants. I find this regrettable, and it is my belief that future international development research projects must necessarily include a strong KT and KM component (described in further detail below).

8.4 Implications for public health education, policy, and practice

Beyond recognizing obesity and diabetes as a problem, government agencies have been slow to implement successful programs to prevent and combat the growing problem of diabetes in India (Khandelwal & Reddy 2013). The findings in this thesis have several implications for food, agriculture, and health policy and practice:

- ***Government nutrition schemes such as the PDS should provide nutritious foods*** such as whole grains, fruits, vegetables, and micronutrient supplements. Iron-fortified and vitamin A-fortified foods could reduce micronutrient deficiencies. Securing coarse cereals and other goods from rainfed regions could also contribute to economic development of overlooked and marginalized areas.
- ***Gender equality,*** both intra-household and in the population at large, should be addressed as a central pillar of food security, public health, and clinical practice.
- ***Healthcare practitioners should be trained*** regarding explanatory models and perceptions of diabetes to ensure the care they provide is culturally sensitive and locally relevant. Mental and physical health should be addressed in tandem.

- ***Government and NGOs should explore ways to educate*** families about the importance of good nutrition, including proper food labeling, advice on nutritional food selection, and food preparation.
- ***A consolidated public health education and policy campaign*** must address the problem of tobacco consumption in rural India. Such a campaign would need to effectively tackle both smoking and chewing tobacco.
- ***Public health messaging aimed at altering cultural perceptions of physical activity would be beneficial***. NGO and government-organized events (e.g. Beat Diabetes walk-a-thon, http://www.beatdiabetes.in/) have had some success in urban areas of India, and such events could target rural regions to increase the acceptance of leisure exercise.

8.5 Recommendations for future research

Based on qualitative and quantitative findings presented in this thesis, the following recommendations are made for future research:

- ***Continued surveillance of under-nutrition, obesity, NCDs, and the double burden of malnutrition:*** Economic development will continue to drive changes in income, lifestyle, and food environments, and India will likely experience increased prevalence of obesity and obesity-related NCDs (Pradeepa et al. 2002). If current trends in under-nutrition and micronutrient deficiencies persist, the national, household, and individual-level double burden of malnutrition may become an increasing public health issue, both in urban and rural regions (Jones et al. 2016). Surveillance studies, conducted by independent researchers, NGOs, and government agencies, must ensure trends are monitored and this information is used to justify further research and policy change.

- ***Inter-disciplinary research on nutrition and health outcomes is a crucial step forward***: Nutrition and NCD research is usually approached from a single disciplinary lens. Epidemiology research groups conduct extensive research on NCDs in India (e.g. the Madras Diabetes Research Foundation, the Indian Council of Medical Research). Others examine these issues through the disciplines of economics, anthropology, and political science. However, nutrition and associated health outcomes are complex and require expertise from researchers and practitioners from numerous disciplines (Choi & Pak 2006), and trans-disciplinary research results in a deeper, more robust understanding of the complexities and interrelationships between nutrition and health (Harriss 2002).
- ***Food policy in India is likely altering food consumption habits, and further research is needed to elucidate the subsequent health effects***
  Food policy in India is characterized by 'caloric fundamentalism' (Headey et al. 2011), the primary goal of which is to improve caloric intake. Unfortunately, such policies appear less concerned with the relative nutritional quality of the foods they provide. While quantitative findings were inconclusive, our qualitative data suggest that the Public Distribution System is shifting food intake patterns, with potential implications for the burdens of micro-nutrient deficiencies, obesity, diabetes, and the double burden of malnutrition. Such findings are alarming, and the impacts of such policies must be explored in further detail to drive evidence-based improvements to Indian food policy.
- ***Researchers must develop valid and reliable tools for collecting food consumption data in low- and middle-income country contexts:*** While some 'gold standard' techniques for assessing dietary intake characteristics have been developed (e.g. doubly

labeled water and urinary nitrogen excretion), epidemiologists in LMIC settings still rely almost entirely on the FFQ and 24-h dietary recall data to explore consumption habits. The limitations of both the FFQ and 24-h dietary recalls are well known and discussed in this thesis. Considering the importance of dietary intake as causes of malnutrition, micronutrient deficiencies, obesity, diabetes, and the double burden of malnutrition, it is crucial that researchers explore options for increasing the validity and reliability of existing tools, or develop entirely new and better tools. Food atlases and portion sizing kits may increase the validity of FFQ data (Nöthlings et al. 2007). Food diaries and diet quality indices show some promise as well, although their usefulness may be limited among uneducated and illiterate populations (Craig et al. 2016; Jain 2014). However, further exploration and validation of dietary measurement tools is crucial.

- ***The concept of the urban/rural divide is outdated and should be abandoned for measures 'rurality' or 'urbanicity'***

  Our rurality index was associated with many dietary intake and health outcomes, suggesting that rural regions may experience a gradient of rurality that affects their dietary, lifestyle, and disease patterns. This finding challenges the definitions employed by Census India, and adopted by many epidemiology researchers in India, that dichotomizes rural and urban populations. While no gold standard exists for measuring rurality or urbanicity, some researchers have employed indices (e.g. Novak et al. 2012) and nighttime light intensity (Jones et al. 2016). Future research should develop, validate, and utilize measures of rurality or urbanicity to challenge the traditional dichotomy of the rural/urban divide in India.

- ***Community engagement and meaningful partnerships are crucial in global health research, and graduate students should be trained and empowered to pursue important KT/KM activities***: Graduate students in global health studies must navigate a daunting research landscape that requires a balance of academic requirements, career ambitions, and research, often in challenging settings. Graduate student training emphasizes theory, study design, data analysis, and academic writing; however, it may overlook the most difficult aspect of graduate student research – namely, the 'research experience', which often requires students to address issues of power and positionality and form strong local collaborations for the mutual benefit of the academic and local community. The quantity and quality of academic outputs are the metric by which students are evaluated, which may limit students to data-collecting activities and restrict their capacity to develop non-academic outputs that may have greater relevance for community partners. Indeed, despite popular rhetoric regarding the importance of long-term sustainable partnerships, 'parachute' research efforts by graduate students are regularly celebrated as successes. Universities and funding agencies should re-evaluate the structures within which we train and evaluate graduate students, and centralize the needs of community partners.
- ***More research:*** Building from the research presented in this thesis, we recommend the following questions that warrant future investigation:
    - Is Barry Popkin's 'nutrition transition' model relevant to modern India? Will urban and rural regions of India enter "stage 5" of the nutrition transition, in which public health education and collective health concerns drive a shift towards exercise for leisure and healthy eating habits (Popkin 1993)?

- How does caste contribute to risk of obesity, NCDs, and the double burden of malnutrition in India? Do caste genetics play a role?
- How does the Public Distribution System alter food consumption habits? Do individuals commonly sell products obtained through the PDS?
- Can India feasibly incorporate whole grains, fruits, and vegetables into the Public Distribution System to promote consumption of healthy foods?
- How can research on food environments be successfully adapted from high-income countries to LMICs?
- How can research on nutrition, obesity, and diabetes incorporate meaningful engagement with research communities aimed at driving healthy dietary and lifestyle changes?
- What effects does gender have on access to nutritious foods in the household and in Indian rural society? Do household gender dynamics change with socioeconomic status, caste, rurality, religion, and household size?
- Are co-morbidities of measures of under- and over-nutrition increasing in India? If so, are these co-morbidities linked in a pathophysiological manner? What risk factors are associated with the double burden of malnutrition?

8.6 Concluding remarks

This thesis describes a mixed-methods approach to examine the issues of obesity, diabetes, the double burden of malnutrition, and the food environment in a rural region of Tamil Nadu, India. High prevalence estimates of overweight, obesity, pre-diabetes, diabetes, underweight, anemia, and other health outcomes provide further evidence for the growing public health crises of nutrition-related deficiencies and excesses and NCDs in India.

Qualitative findings and quantitative associations between risk factors and health outcomes provide important information for informing public health, planning, prioritization, and programming in rural regions of India. Future research is needed to further understand these issues and design evidence-based solutions.

REFERENCES

Aigner, E., Feldman, A., & Datz, C. (2014). Obesity as an emerging risk factor for iron deficiency. *Nutrients*, *6*(9), 3587-3600.

Agrawal, R. P., Singh, G., Nayak, K. C., Kochar, D. K., Sharma, R. C., et al. (2004). Prevalence of diabetes in camel-milk consuming Raica rural community of north-west Rajasthan. *International Journal of Diabetes in Developing Countries*, *24*, 109-14.

Agrawal, S., & Ebrahim, S. (2012). Prevalence and risk factors for self-reported diabetes among adult men and women in India: findings from a national cross-sectional survey. *Public Health Nutrition*, *15*(06), 1065-1077.

Ajay, V. S., Prabhakaran, D., Jeemon, P., Thankappan, K. R., Mohan, V., et al. (2008). Prevalence and determinants of diabetes mellitus in the Indian industrial population. *Diabetic Medicine*, *25*(10), 1187-1194.

Anjana, R. M., Pradeepa, R., Deepa, M., Datta, M., Sudha, V., et al. (2011). Prevalence of diabetes and prediabetes (impaired fasting glucose and/or impaired glucose tolerance) in urban and rural India: Phase I results of the Indian Council of Medical Research–INdia DIABetes (ICMR–INDIAB) study. *Diabetologia*, *54*(12), 3022-3027.

Astrup, A., & Finer, N. (2000). Redefining type 2 diabetes: ‘diabesity’ or ‘obesity dependent diabetes mellitus’? *Obesity Reviews*, *1*(2), 57-59.

Barcellos, S. H., Carvalho, L. S., & Lleras-Muney, A. (2014). Child gender and parental investments in India: are boys and girls treated differently? *American Economic Journal: Applied Economics*, *6*(1), 157-189.

Behrman, J. R. (1988). Intrahousehold allocation of nutrients in rural India: Are boys favored? Do parents exhibit inequality aversion? *Oxford Economic Papers*, *40*(1), 32-54.

Choi, B. C., & Pak, A. W. (2006). Multidisciplinarity, interdisciplinarity and transdisciplinarity in health research, services, education and policy: 1. Definitions, objectives, and evidence of effectiveness. *Clinical and Investigative Medicine*, *29*(6), 351.

Coffey, D. (2017). When women eat last. *The Hindu, Jan. 7th 2017 edition.* Available at: http://www.thehindu.com/opinion/op-ed/When-women-eat-last/article16978948.ece?homepage=true. Accessed 16 March 2017.

Craig, L. C. A., McNeill, G., Masson, L. F., & Macdiarmid, J. I. (2016). Relative validity of a diet quality index for children in Scotland. *The Proceedings of the Nutrition Society*, *75*(OCE3).

De Benoist, B., McLean, E., Egli, I., & Cogswell, M. (2008). Worldwide prevalence of anaemia 1993-2005: WHO global database on anaemia. *Geneva: WHO*. Available at:

http://apps.who.int/iris/bitstream/10665/43894/1/9789241596657_eng.pdf. Accesse 3 April 2017.

Desai, S., & Vanneman, R. (2012). India Human Development Survey II (IHDS-II). [TSV dataset]. Available at: http://ihds.info/. Acceessed 16 March 2017.

Eckhardt, C. L., Torheim, L. E., Monterrubio, E., Barquera, S., & Ruel, M. T. (2008). The overlap of overweight and anaemia among women in three countries undergoing the nutrition transition. *European Journal of Clinical Nutrition, 62*(2), 238-246.

Fewell, Z., Smith, G. D., & Sterne, J. A. (2007). The impact of residual and unmeasured confounding in epidemiologic studies: a simulation study. *American Journal of Epidemiology*, *166*(6), 646-655.

Furukawa, S., Fujita, T., Shimabukuro, M., Iwaki, M., Yamada, Y., et al. (2004). Increased oxidative stress in obesity and its impact on metabolic syndrome. *The Journal of Clinical Investigation*, *114*(12), 1752-1761.

Gillespie, S., & Haddad, L. (2003). *The double burden of malnutrition in Asia: causes, consequences, and solutions*. Sage Publications India.

Gupta, R., Joshi, P., Mohan, V., Reddy, K. S., & Yusuf, S. (2008). Epidemiology and causation of coronary heart disease and stroke in India. *Heart*, *94*(1), 16-26.

Gupta, S. K., Singh, Z., Purty, A. J., Kar, M., Vedapriya, D. R., Mahajan, P., & Cherian, J. (2010). Diabetes prevalence and its risk factors in rural area of Tamil Nadu. *Indian Journal of Community Medicine*, *35*(3), 396.

Hamilton, C., & Filardo, G. (2006). The dangers of categorizing body mass index. *European Heart Journal*, *27*(23), 2903-2904.

Harriss, J. (2002). The case for cross-disciplinary approaches in international development. *World Development, 30*(3), 487-496.

Headey, D., Chiu, A., & Kadiyala, S. (2011). *Agriculture's role in the Indian enigma: Help or hindrance to the undernutrition crisis?* (No. 1085). International Food Policy Research Institute (IFPRI). Available at: https://ideas.repec.org/p/fpr/ifprid/1085.html. Accessed 3 April 2017.

He, K., Hu, F. B., Colditz, G. A., Manson, J. E., Willett, W. C., & Liu, S. (2004). Changes in intake of fruits and vegetables in relation to risk of obesity and weight gain among middle-aged women. *International Journal of Obesity*, *28*(12), 1569-1574.

Humphreys, J. S. (1998). Delimiting 'rural': implications of an agreed 'rurality'index for healthcare planning and resource allocation. *Australian Journal of Rural Health*, *6*(4), 212-216.

International Institute for Population Sciences (IIPS). (2007). National Family Health Survey (NFHS-3). Mumbai, India: IIPS. Available at: http://rchiips.org/nfhs/NFHS-3%20Data/VOL-1/India_volume_I_corrected_17oct08.pdf. Accessed 16 Feb 2017.

Jain, A. & Mathur, P. (2014). Intake of processed foods and selected food additives among teenagers (13-19 years old) of Delhi, India. *Asian Journal of Multidisciplinary Studies*, *2*(2).

Jo, Y. H., Talmage, D. A., Role, L. W. (2002). Nicotinic receptor-mediated effects on appetite and food intake. *Journal of Neurobiology, 53*(4), 618-632.

Jones, A. D., Hayter, A. K., Baker, C. P., Prabhakaran, P., Gupta, V., et al. (2016). The co-occurrence of anemia and cardiometabolic disease risk demonstrates sex-specific sociodemographic patterning in an urbanizing rural region of southern India. *European Journal of Clinical Nutrition*, *70*(3), 364-372.

Karthikeyan, M., Jena, D., Patel, K., Khadka, K., Devkota, R., Samaratunga, H., & Sakkari, K. (2012). Baseline Survey in Project Sites: A Report as a Part of 'Revalorizing Small Millets in the Rainfed Regions of South Asia (RESMISA)', India, Nepal, Sri Lanka and Canada: DHAN Foundation, Arthacharya Foundation, Local Initiatives for Biodiversity, Research and Development (LIBIRD) and Canadian Mennonite University.

Kaur, P., Rao, S. R., Radhakrishnan, E., Ramachandran, R., Venkatachalam, R., & Gupte, M. D. (2011). High prevalence of tobacco use, alcohol use and overweight in a rural population in Tamil Nadu, India. *Journal of Postgraduate Medicine*, *57*(1), 9.

Khandelwal, S., & Reddy, K. S. (2013). Eliciting a policy response for the rising epidemic of overweight-obesity in India. *Obesity Reviews*, *14*(S2), 114-125.

Kokiwar, P. R., Gupta, S., & Durge, P. M. (2007). Prevalence of diabetes in a rural area of central India. *International Journal of Diabetes in Developing Countries*, *27*(1), 8-10.

Kuriyan, R., Bhat, S., Thomas, T., Vaz, M., & Kurpad, A. V. (2007). Television viewing and sleep are associated with overweight among urban and semi-urban South Indian children. *Nutrition Journal*, *6*(1), 25.

Martín-Moreno, J. M., Boyle, P., Gorgojo, L., Maisonneuve, P., Fernandez-rodriguez, J. C., Salvini, S., & Willett, W. C. (1993). Development and validation of a food frequency questionnaire in Spain. *International Journal of Epidemiology*, *22*(3), 512-519.

Misra, R., Misra, A., Kamalamma, N., Vikram, N. K., Gupta, S., et al. (2011). Difference in prevalence of diabetes, obesity, metabolic syndrome and associated cardiovascular risk factors in a rural area of Tamil Nadu and an urban area of Delhi. *International Journal of Diabetes in Developing Countries*, *31*(2), 82-90.

Mohan, V., Mathur, P., Deepa, R., Deepa, M., Shukla, D. K., et al. (2008). Urban rural differences in prevalence of self-reported diabetes in India—The WHO–ICMR Indian NCD risk factor surveillance. *Diabetes Research and Clinical Practice*, *80*(1), 159-168.

Mohan, V., Radhika, G., Vijayalakshmi, P., & Sudha, V. (2010). Can the diabetes/cardiovascular disease epidemic in India be explained, at least in part, by excess refined grain (rice) intake? *The Indian Journal of Medical Research*, *131*, 369-72.

National Nutrition Monitoring Bureau. (2006). Diet and nutritional status of population and prevalence of hypertension among adults in rural areas. Available at: http://nnmbindia.org/nnmbreport06nov20.pdf. Accessed 8 February 2017.

Nöthlings, U., Hoffmann, K., Bergmann, M. M., & Boeing, H. (2007). Fitting portion sizes in a self-administered food frequency questionnaire. *The Journal of Nutrition*, *137*(12), 2781-2786.

Novak, N. L., Allender, S., Scarborough, P., & West, D. (2012). The development and validation of an urbanicity scale in a multi-country study. *BMC Public Health*, *12*(1), 530.

Oommen, A. M., Abraham, V. J., George, K., & Jose, V. J. (2016). Prevalence of risk factors for non-communicable diseases in rural & urban Tamil Nadu. *Indian Journal of Medical Research*, *144*(3), 460.

Osmani, S., & Sen, A. (2003). The hidden penalties of gender inequality: fetal origins of ill-health. *Economics & Human Biology*, *1*(1), 105-121.

Perkins, K. A., Epstein, L. H., Stiller, R. L., Marks, B. L., & Jacob, R. G. (1989). Acute effects of nicotine on resting metabolic rate in cigarette smokers. *The American Journal of Clinical Nutrition*, *50*(3), 545-550.

Persson, P. G., Carlsson, S., Svanström, L., Östenson, C. G., Efendic, S., & Grill, V. (2000). Cigarette smoking, oral moist snuff use and glucose intolerance. *Journal of Internal Medicine*, *248*(2), 103-110.

Popkin, B. M. (1993). Nutritional patterns and transitions. *Population and Development Reviews*, 138-157.

Pradeepa, R., Deepa, R., & Mohan, V. (2002). Epidemiology of diabetes in India--current perspective and future projections. *Journal of the Indian Medical Association*, *100*(3), 144-148.

Priya, M., Mohan Anjana, R., Pradeepa, R., Jayashri, R., Deepa, M., Bhansali, A., & Mohan, V. (2011). Comparison of capillary whole blood versus venous plasma glucose estimations in screening for diabetes mellitus in epidemiological studies in developing countries. *Diabetes Technology & Therapeutics*, *13*(5), 586-591.

Purkayastha, B., Subramaniam, M., Desai, M., & Bose, S. (2003). The study of gender in India: A partial review. *Gender & Society*, *17*(4), 503-524.

Radhika, G., Sathya, R. M., Ganesan, A., Saroja, R., Vijayalakshmi, P., Sudha, V., & Mohan, V. (2011). Dietary profile of urban adult population in South India in the context of chronic disease epidemiology (CURES–68). *Public Health Nutrition*, *14*(04), 591-598.

Radhika, G., Van Dam, R. M., Sudha, V., Ganesan, A., & Mohan, V. (2009). Refined grain consumption and the metabolic syndrome in urban Asian Indians (Chennai Urban Rural Epidemiology Study 57). *Metabolism*, *58*(5), 675-681.

Riha, J., Karabarinde, A., Ssenyomo, G., Allender, S., Asiki, G., et al. (2014). Urbanicity and lifestyle risk factors for cardiometabolic diseases in rural Uganda: a cross-sectional study. *PLoS Medicine*, *11*(7), e1001683.

Rimm, E. B., Chan, J., Stampfer, M. J., Colditz, G. A., & Willett, W. C. (1995). Prospective study of cigarette smoking, alcohol use, and the risk of diabetes in men. *British Medical Journal*, *310*(6979), 555-559.

Royston, P., Altman, D. G., & Sauerbrei, W. (2006). Dichotomizing continuous predictors in multiple regression: a bad idea. *Statistics In Medicine*, *25*(1), 127-141.

Sudha, V., Radhika, G., Sathya, R. M., Ganesan, A., & Mohan, V. (2006). Reproducibility and validity of an interviewer-administered semi-quantitative food frequency questionnaire to assess dietary intake of urban adults in southern India. *International Journal of Food Sciences and Nutrition*, *57*(7-8), 481-493.

Taylor, J. M., & Yu, M. (2002). Bias and efficiency loss due to categorizing an explanatory variable. *Journal of Multivariate Analysis*, *83*(1), 248-263.

Thompson, K. H., & Godin, D. V. (1995). Micronutrients and antioxidants in the progression of diabetes. *Nutrition Research*, *15*(9), 1377-1410.

Venkatachalam, J., Prasad, V., Muthu Kumar, T., Samuel, A. K., & Singh, Z. (2016). Prevalence and determinants of systemic hypertension among 15-year and older respondents in a rural area of Kancheepuram district, Tamil Nadu—a cross-sectional study. *International Journal of Medical Science and Public Health*, *5*(7), 1433-1438.

Weinert, C., & Boik, R. (1995). MSU Rurality Index: Development and evaluation. *Research in Nursing and Health,18*, 453-464.

Willi C, Bodenmann P, Ghali WA, Faris PD, Cornuz J. (2007). Active smoking and the risk of type 2 diabetes: A systematic review and meta-analysis. *Journal of the American Medical Association*, *298*(22):2654-2664.

World Health Organization. (2005). WHO STEPS surveillance manual: the WHO STEPwise approach to chronic disease risk factor surveillance. Available at: http://www.who.int/ncd_surveillance/en/steps_framework_dec03.pdf. Accessed 4 March 2017.

World Health Organization. (2006). Definition and diagnosis of diabetes mellitus and intermediate hyperglycaemia: report of a WH. Available at: http://apps.who.int/iris/bitstream/10665/43588/1/9241594934_eng.pdf. Accessed 12 Jan 2017.

World Health Organization. (2011). World Health Organization. Global Physical Activity Questionnaire (GPAQ) Analysis Guide. Available at: http://www.who.int/chp/steps/resources/GPAQ_Analysis_Guide.pdf. Accessed 3 April 2017.

Zimmermann, M. B., Zeder, C., Muthayya, S., Winichagoon, P., Chaouki, N., Aeberli, I. et al. (2008). Adiposity in women and children from transition countries predicts decreased iron absorption, iron deficiency and a reduced response to iron fortification. *International Journal of Obesity, 32*, 1098–1104.

TABLES

Table 8.1 Prevalence of health outcomes in a cross-sectional study of 753 adults in a rural region of Tamil Nadu

Health outcome	**Crude prevalence (%)**		**p-value***
	Men (n=341)	Women (n=412)	
Underweight (BMI <18.5)	24.7	21.0	0.19
Overweight (BMI ≥23 kg/m^2 and <25 kg/m^2)	16.5	15.3	0.61
Obesity Class I (BMI ≥25 kg/m^2 and <30 kg/m^2)	16.2	19.0	0.36
Obesity Class II (BMI ≥30 kg/m^2)	1.8	4.9	0.021
Impaired fasting glucose	2.1	3.2	0.34
Impaired glucose tolerance	6.2	6.4	0.91
Type 2 diabetes			
Previously diagnosed	5.0	4.7	0.83
Previously undiagnosed	7.9	6.1	0.33
Total	12.9	10.8	0.40
High blood pressure	31.1	28.8	0.51
Mild, moderate, or severe anemia	35.7	60.0	<0.001

*P-value is for Pearson's chi-square comparing prevalence differences between men and women

APPENDIX 1: Calculation of household asset (wealth) index for analyses in Chapters 3,4, 6, and 7

Table A1.1: Summary of household assets and scores used to calculate wealth index

Household Asset	Score[1]
House Type	
Pucca (concrete)	4
Semi-pucca (concrete walls, thatched roof)	2
Kutcha (mud walls, thatched roof)	0
Ownership of house	
No	0
Yes	2
Toilet Facility	
Public or shared toilet	0
Own indoor toilet	4
Source of drinking water	
Tap in residence/yard/plot	3
Public tap	2
Bore well/hand pump	1
Open well	0
Land ownership	
None	0
>0 but <2 acres	2
2.0 – 4.9 acres	3
>5 acres	4
Ownership of:	
Mobile phone	3
Television	2
Clock	1
Radio	2
Livestock (>0 animals)	2
Bicycle	2
Motorcycle	3
Vehicle (3-wheeled)	4
Vehicle (4-wheeled)	5

[1]Scores adapted from: International Institute for Population Sciences. (1999). Standard of Living Index: National Family and Health Survey-2. Available at: http://www.dhsprogram.com/pubs/pdf/FRIND2/FRIND2.pdf. Accessed 4 Nov 2013.

APPENDIX 2: List of all variables assessed in linear and logistic regression models in Chapters 3,4, and 6

Non-dietary:
Age, sex, rurality index, wealth index, family history of diabetes BMI, waist-to-hip ratio, waist circumference, physical activity score, television screen time, sedentary time, education (number of years of formal schooling), participation in agriculture, type of agriculture (subsistence, local sale, commercial), participation in National Rural Employment Guarantee Act, local business owner, day labourer, high caste, low caste, vehicle ownership, television ownership, land ownership, migrant labourer, water source, hypertension, livestock owner, Hindu, Muslim, Christian, type of house (kutcha, semi-pucca, or pucca), water access (tap water, bore well, open well) smoking, smokeless tobacco user, general tobacco user (smoking or smokeless combined), total energy intake, family history of diabetes, literate, (caste)*(sex), (wealth index)*(sex), (millet consumption)*(rurality index), (physical activity)*(television screen time), (physical activity)*(sedentary time), $[age]^2$, $[land\ ownership]^2$

Dietary – intake of (g/1000kcal consumed unless otherwise specified):
Carbohydrates, proteins, fats, millets, refined grains, whole wheat, leafy vegetables, root and tuber vegetables, other vegetables, total vegetables, meat, poultry, nuts and seeds, pulses, fruits, milk products, refined sugar, salt, total dietary fibre, insoluble dietary fibre, soluble dietary fibre, total fats, total oils, n-3 polyunsaturated fatty acids, n-6 polyunsaturated fatty acids, n-3 PUFA:n-6 PUFA (ratio), total polyunsaturated fatty acids, saturated fatty acids, monounsaturated fatty acids, alcohol, cholesterol, iron (mg/day), vitamin A (ug/day), calcium (mg/day)

APPENDIX 3: Supplementary tables

Table A3.1: Energy-adjusted consumption of food groups and macronutrients in a sample of 753 adults (>19 years) in rural Tamil Nadu

	Intake mean ± SD		
Foods (g/1000 kcal unless otherwise specified)	**Women (n=411)**	**Men (n=341)**	**p-value**
Calories (kcal/day)	2219 ±629	2583 ±800	<0.001
Food groups			
Rice and rice products	70.0 ±32.3	63.5 ±31.9	0.006
Wheat and wheat products	9.81 ±10.8	8.3 ±9.4	0.05
Coarse cereals (e.g. millets, sorghum)	96.8 ±60.5	99.4 ±58.8	0.54
Pulses and pulse products	28.4 ±11.6	26.5 ±3.8	0.03
Milk and milk products	71.4 ±60.0	92.1 ±75.0	<0.001
Eggs, fish, and meat	3.2 ±5.8	3.8 ±6.2	0.17
Leafy vegetables	6.3 ±7.5	5.5 ±6.4	0.10
Other vegetables	10.9 ±9.5	9.6 ±8.6	0.06
Total vegetables	38.3 ±31.8	37.8 ±38.8	0.88
Roots and tubers	26.9 ±13.3	25.9 ±13.5	0.28
Fruit	63.4 ±49.8	56.1 ±42.1	0.03
Protein	25.7 ±1.7	25.6 ±2.1	0.35
Carbohydrates	180.9 ±12.8	178.0 ±16.2	0.006
Fats	19.8 ±5.4	19.5 ±5.2	0.42
Dietary fibre	22.3 ±4.9	21.6 ±7.4	0.08
Sugar	11.2 ±9.8	14.0 ±12.5	<0.001
Salt	6.2 ±2.5	6.0 ±2.2	0.008

Table A3.2: Consumption of food groups in rural Tamil Nadu and the study group compared to National Sample Survey Organization sample averages

Foods (kg/day unless otherwise stated)	NSSO national averages 1999-2000[1]	NSSO national averages 2009-10[1]	Study group, average ±SD
Food groups			
Rice and rice products	9.81	10.12	4.65 ±2.44
Wheat and wheat products	0.20	0.435	0.63 ±0.70
Coarse cereals (e.g. millets, sorghum)	0.65	0.424	7.10 ±5.25
Total cereals	10.66	10.98	12.38
Pulses and pulse products	0.83	0.831	1.92 ±0.99
Milk and milk products	2.60	3.216	5.96 ±5.69
Edible oils, total	0.43	0.610	0.66 ±0.39
Eggs, fish, and meat	0.50	0.845	0.38 ±0.50
Leafy vegetables	NA	NA	0.41 ±0.55
Other vegetables	NA	NA	0.73 ±0.67
Total vegetables	4.04	4.8	1.27 ±1.01
Roots and tubers	NA	NA	1.94 ±1.07
Fruit	0.98	1.20	4.31 ±3.93
Calories (kcal)	NA	NA	2384 ±734
Protein (g/day)	NA	NA	61 ±18.6
Carbohydrates (g/day)	NA	NA	426.6 ±130.7
Dietary fibre (g/day)			52.3 ±20.4
Sugar, total	0.53	0.585	0.92 ±0.94
Other nutrients			
Iron (mg/day)	NA	NA	13.8 ±6.6
Calcium (mg/day)	NA	NA	564 ±289
Vitamin A (μg/day)	NA	NA	2125 ±2312
Vitamin C (mg/day)	NA	NA	90.3 ±99.2

Acronyms**:** NSSO, national sample survey organization
[1]Data taken from: National Sample Survey Organization. (2010). Household Consumption of Various Goods and Services. Available at: http://164.100.34.62/index.php/catalog/19/download/1044. Accessed 10 February 2017.

APPENDIX 4: Heads of households semi-structured interview guide, asked of 61 individuals from 61 households in four *panchayats* in rural Tamil Nadu, India, selected using a snowball sampling approach

General introductory questions

- Town and panchayat
- Name
- Age
- Number of people in household?
- Are you a landowner? If so, how much land and type of crops grown?
- Do you have any jobs apart from your land and family duties (ex. Do you have a store or sell anything you make?)
- Do you sell any of your crops, or do you keep all of the produce for your family?

General Health Questions

- What are some of the health problems that you commonly see in this village?
- Which of these do you believe to be most concerning (top 3)?
- Are these curable? How and why do they occur? Do you miss work as a result of these conditions?
- Are you worried about your health or the health of your family?
- What do people you do when they get sick in this village? Do they seek or partake in:
    - Professional medical help (hospital in Anchetty or Denkeni)?
    - Traditional medicine (herbal remedies or ayurvedic medicine)?
    - Local chemists?

Diabetes Questions

- What is diabetes?
- Is diabetes a significant concern in this village, or to you? Why or why not, considering it is a large problem in other places?
- Do you know anyone with diabetes? If so, how many people? How does diabetes affect the lives of people?
- What causes diabetes in this area? Is diabetes related to nutrition?
- How can people treat diabetes? Traditional Medicine? Modern medicine? Herbal remedies? Changes in diet or exercise?
- Are you aware of any services in the area that are available for diabetics?
- Did you know that diabetes could lead to eye problems, kidney problems, and heart problems?
- Would you be interested in education workshops for diabetics?

Nutrition Questions

- How do you choose the food to eat every day?
- Does your food affect your health in a positive or negative way?
- (If owns land) Do you eat the food that you produce?
- What do you eat for breakfast, lunch, and dinner, on average? Snacks throughout the day?

- How often do you eat vegetables?
- Do you consume enough food to keep you strong?
- Do you use the public distribution system to get free grain? What do you think of that system? Is the food good quality?
- Group the following foods into ‘healthy’, ‘unhealthy’, or ‘neither healthy nor unhealthy’:
    - **Individual foods:**
      Ragi, rice (PDS), rice (from private shop), rice (home-grown), puffed rice, vegetables, pulses, oil, sugar, coconuts, fruits, vegetables, potatoes, spices, salt
    - **Full Meals and prepared foods**
      Pani puri, Biryani, Ragi ball, masala dosai, idli, sweets, cake, bread, chapatti, roti, puri, biscuits (sweet), biscuits (salty), oil snacks, egg puffs, tea (with sugar), tea (witout sugar), coffee (with and without sugar), sambar, daal, cool drinks

Anemia

- What is anemia? (If correct, move on. If not, say: Anemia is when people don’t consume enough iron and it makes them tired and weak. Does this sound like something that is a problem in this village?)
- Is anemia a concern in this village?
- Is anemia connected to diet? What can one do to prevent or treat anemia?

Joint Pain

If interviewee mentions joint pain as a significant concern, can speak further about this issue and how it affects them. Inquire about causes and cures, and if it has been increasing. Age of onset?

Health Care

- How many times per year do you visit the hospital/doctor/health clinic?

- Have you, or anyone in your household, been sick in the past year? Can you tell us about that experience?

    - What were your symptoms?
    - Did you seek treatment?
      If you went to a government or private hospital:
      -how long did the drive or walk take?
      -how long did you have to wait?
      -what condition did the doctor diagnose you with?
      -what did the doctor do for you?
      -how did the doctor treat you?
      -Did he educate you or tell you how to prevent the condition from occurring again?
      -were you satisfied with the treatment you received?
      -why did you choose to go treat the condition this way instead of another (ie private instead of public, public instead of private, or hospital instead

of home remedies or seeking an ayurvedic/traditional medicine specialist?)

APPENDIX 5: Semi-structured guide for interviews with individuals with diabetes (n=54), recruited using convenience and snowball sampling approaches, in a rural region of Tamil Nadu, India

1) **Audiotaped Narrative**
   Please tell the story about your diabetes – what caused it, when did it start, what did you do about it, and how has it progressed until now.
   Potential prompts:
   -When did you first know that something was wrong?
   -What were your symptoms?
   -What caused your diabetes?
   -Did you go to a hospital?
   -When were you diagnosed?
   -How has the disease progressed since diagnosis?

2) **Semistructured interview**
   a) **Personal medical history**
      a. *Did you suffer any diseases or health problems BEFORE diabetes?*
      b. *Have you suffered from any health problems AS A RESULT OF your diabetes?*
   b) **Psychological reaction to diagnosis**
      a. *When you were diagnosed with diabetes, what did you think?*
      b. *Were you stressed or anxious?*
      c. *Were you angry?*
      d. *Were you sad?*
      e. *Were you worried?*
         -worried about the cost?
         -worried about your health?
         -worried about your ability to work or earn income?
   c) **Medication/Treatment**
      a. *Do you test yourself regularly using a glucometer or a urine sampler?*
      b. *Are you currently on medication?*
         If 'yes', ask:
         -What medications?
         -Where do you buy the medication?
         -How much do you pay for medication per month?
         -Does the medicine work?
         -Are there any side effects?
         -Have you ever used traditional or natural medicine?
   d) **Preference of Private/Public/Traditional Medicine**
      a. *Where did you receive a diagnosis?*
         i. *WHY did you choose that particular service?*
         ii. *How much did you pay for the initial diagnosis?*
      b. *Where do you go for check-ups?*
         i. *WHY do you choose to go to that particular service?*
         ii. *How often do you go for a check-up?*

        iii. *How much do you pay for each check-up?*
    c. *Have you ever used traditional medicine?*
       If yes,
        i. *Where did you go to receive the medicine?*
        ii. *What did they give you?*
        iii. *Did it work?*
        iv. *Do you still believe in traditional medicine?*
    d. *Are you satisfied with the services you currently receive?*
        i. *Are the doctors polite?*
        ii. *Do they speak the same language that you do?*
        iii. *Do they provide good information and treatment advice?*
    e. *In your opinion, is the government hospital better than private services or vice versa?*
        i. *WHY?*

e) Knowledge about causes, complications, and treatment objectives

    a. *What happens inside your body when you get diabetes?*
    b. *In your opinion, what causes diabetes?*
       -If 'I don't know', prompt:
       -poor diet?
       -poor exercise?
       -stress?
       -family history?
       -smoking?
       -obesity?
        i. *Which, if any, of those causes resulted in YOUR diabetes?*
    c. *What are the symptoms of diabetes?*
       -If 'I don't know', prompt:
       -numbness of hands and feet?
       -polydypsia (increased thirst)?
       -polyuria (increased urination)?
       -fatigue/tiredness?
       -fainting (going unconscious)?
       -eye problems?
       -kidney problems?
       -heart problems?
       -infections and amputations of fingers and toes?
    d. *What can you do to control your diabetes?*
    e. *What complications can arise from diabetes?*
       -if 'I don't know', prompt:
    f. *What are the objectives of your diabetes treatment?*
    g. *Do you want to learn more about diabetes?*
    h. *What is the best way to learn more about diabetes?*

f) Attitude towards dietary change

    a. *How has your diet changed over the past 20 years?*
        i. *Why has your diet changed?*
            1. *Do you produce different foods now?*

2. *Has the PDS impacted your diet?*
   ii. *Is it healthier now than it used to be?*
   iii. *Do you eat better quality of food?*
   iv. *Do you eat more food than you used to?*

b. *Did your doctor provide you with any dietary recommendations?*
   i. *What were the recommendations?*
   ii. *Do you follow those recommendations?*
   If no, why not?

g) Change in physical exercise and attitude toward physical exercise

a. *Do you still work?*
   i. *If yes, how many hours per day and how does this compare to 20 years ago?*
   ii. *If no, how many hours did you work 20 years ago?*
b. *Do you exercise?*
c. *Would you ever exercise for non-work reasons?*
d. *Did your doctor provide you with recommendations about physical exercise?*
   i. *What were the recommendations?*
   ii. *Do you follow those recommendations?*
   If no, why not?

h) Perceived social constraints resulting from diabetes

a. *Is there anything you'd like to be able to do, that you can't do as a result of your diabetes?*
b. *Do people treat you differently because you have diabetes?*
c. *Does your diabetes cause quarrels with your neighbours or friends?*
d. *Does your diabetes cause quarrels with your family?*

i) Smoking and drinking

a. *Do you smoke bidis or any other form of tobacco?*
   If yes,
   i. *How long have you been smoking?*
   ii. *How often?*
   iii. *Does it affect your health?*
b. *Do you drink alcoholic drinks?*
   If yes,
   i. *How many years have you been drinking?*
   ii. *How much/how often?*
   iii. *Does it affect your health?*
   iv. *Does it affect your family relationships?*

j) Gender questionnaire (women only):

1) Have you ever been pregnant? Y N

   a. If yes, how did you change your diet during pregnancy?

Vitamin tablets ☐ More fruit/vegetables ☐ More milk/meat ☐ More ragi/rice

☐ Other ____

2) Who is responsible for purchasing food in the household? ☐ Men ☐ Women

3) Who is responsible for preparing food in the household? ☐ Men ☐ Women

4) What is traditionally the order of eating in the household?

☐ Men eat first ☐ Women eat first ☐ Men and women eat at the same time

5) Do you eat MORE / LESS / THE SAME quantity of food as your significant other?

6) Do you eat MORE / LESS / THE SAME frequently than your significant other?

7) Do you eat BETTER / WORSE / THE SAME quality of food as your significant other?

   If you had only one portion of meat, who in the household would eat that portion?
   ☐ A male ☐ A female ☐ A pregnant female ☐ Children ☐ We would share it
   ☐ Other______________________________________

8) Who controls the household money?
   ____

9) How many hours per day do you work? ________
   a. What type of Work? NREGA / OWN FIELD / SOMEONE ELSE'S FIELD / MIGRANT WORK

10) How many hours per day does your husband/wife work? __________
   a. What type of Work? NREGA / OWN FIELD / SOMEONE ELSE'S FIELD / MIGRANT WORK

Participatory Methods

1) Construction of Family Tree – Drawing, and asking about any health problems of others.

Family History of Diabetes:

a. Does anyone else in your family currently have diabetes?
b. Did your parents or grandparents have diabetes?
c. Do you suspect anyone else had diabetes in your family (i.e. they had symptoms but were never diagnosed)?

2) Group foods into 'permitted' and 'not permitted' then discuss the classification. While doing so, ask 'how many times per day/week/month/year do you consume this item?'

a. Individual foods:

Ragi, rice (PDS), rice (from private shop), rice (home-grown), puffed rice, vegetables, pulses, oil, sugar, coconuts, fruits, vegetables, potatoes, spices, salt

b. **Full Meals and prepared foods**
Pani puri, Biryani, Ragi ball, masala dosai, idli, sweets, cake, bread, chapatti, roti, puri, biscuits (sweet), biscuits (salty), oil snacks, egg puffs, tea (with sugar), tea (witout sugar), coffee (with and without sugar), sambar, daal, cool drinks

3) **'Preferred' and 'Healthy' Body size – a selection of six images, varying in body mass index and the same sex of the interviewee, are sorted into 'most aesthetically preferred' through to 'least preferred' and again into 'most healthy' through 'least healthy**

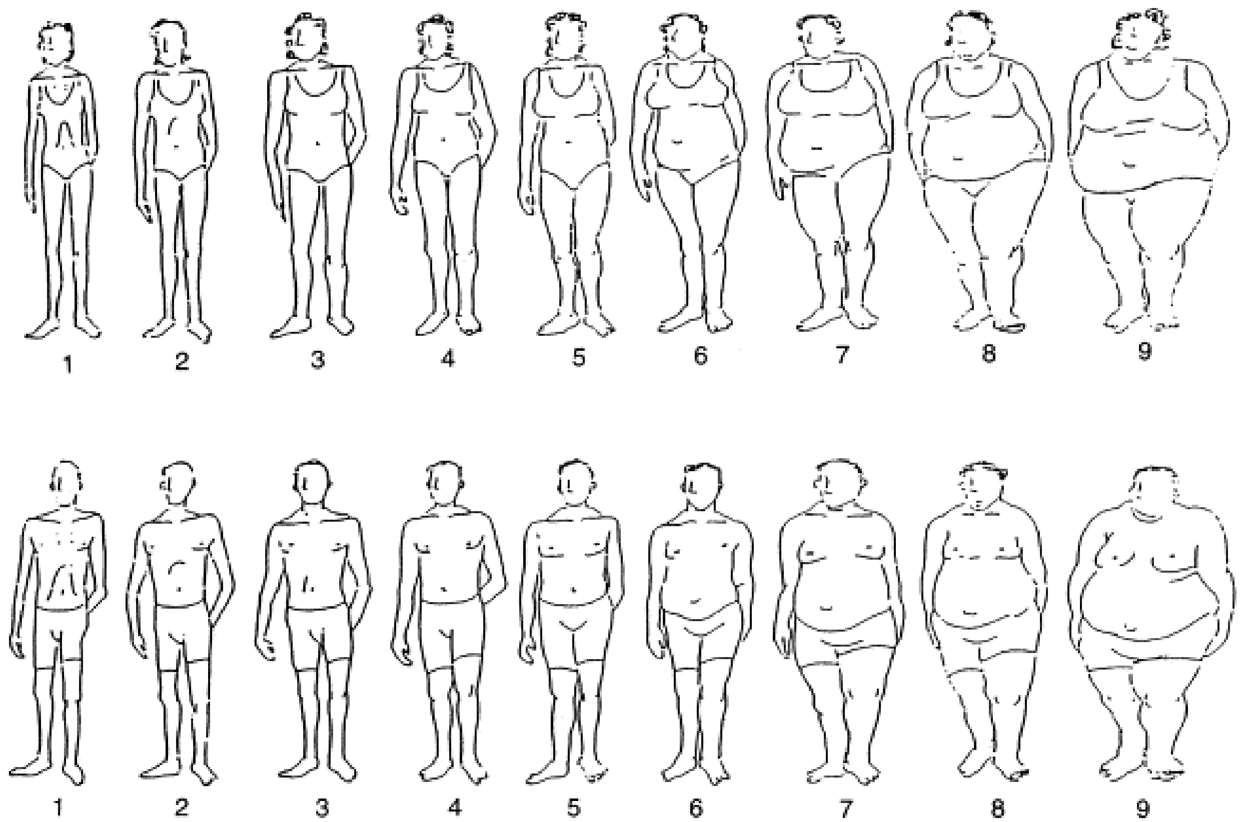

Figure A5.1: Body size chart for 'preferred' and 'healthy' body size selections, interviews with individuals with diabetes

APPENDIX 6: Structured vignette guide, conducted with a sub-sample of individuals with type 2 diabetes (n=8), randomly selected from the original group of 54 participants

Name: Sex: # years with diabetes:

Age: # Members in household: BMI (as measured):

Structured Vignette

Rajapandian is 48 years old and lives in Thakatti panchayat. He was diagnosed with diabetes 5 years ago.

Statement	Agree	Disagree	Don't Know	Comments
Rajapandian believes diabetes wasn't a problem in the Anchetty area before 15 years ago				
Rajapandian believes eating a poor diet and lots of sugar caused his diabetes				
Rajapandian believes rice caused his diabetes and he feels worse after he eats rice.				
Rajapandian only started eating rice when the PDS began providing it through the government shop.				
Rajapandian believes ragi is good for him and doesn't cause diabetes.				
Rajapandian's son died 2 years before, and he believes the stress and grief caused his diabetes				
Rajapandian smokes cigarettes and drinks alcohol, but he doesn't believe these habits caused his diabetes.				
Rajapandian thinks that somebody with diabetes should go to the doctor regularly, even if their symptoms aren't bothering them				
Rajapandian goes to a private doctor in Denkannikotai. He believes private services are better than government services.				
Rajapandian thinks the doctor knows everything about diabetes, and doesn't trust advice from anyone else.				
Rajapandian doesn't like to exercise. He doesn't think he needs to exercise if he is on medication.				
Rajapandian takes tablets to treat his diabetes. He thinks this is the best way to treat his diabetes				
Rajapandian believes that he should avoid sugar items because of his diabetes				
Rajapandian believes that he can still eat all of his favourite foods like dosai, idli, and rice, because he's taking tablets and they control his diabetes.				
Rajapandian doesn't use natural/traditional medicine.				

He doesn’t believe that those remedies will work.				
Rajapandian goes to the temple to pray every day, and he believes that the gods will reward him by curing his diabetes some day.				
Rajapandian thinks that if his diabetes isn’t controlled, it will lead to problems with his eyes, his heart, and his kidneys				
Rajapandian no longer works. He is afraid to work because he believes he can get infections, or faint and fall down, and he’s worried about his health.				
Rajapandian is sad because his neighbours avoid him – they are afraid of catching diabetes.				

APPENDIX 7: Questionnaire for quantitative study applied to 753 randomly-selected adults (>19 years) in two rural *panchayats* in rural Tamil Nadu

UNIVERSITY of GUELPH

DHAN Foundation
Building Institutions for Generations

Study Name: **Food consumption and chronic disease epidemiology in rural Tamil Nadu**

Interviewer Code: ______________ Interview Code: ______________ Start time of Interview: ___________

Date: ________________________ Verbal Consent: ☐ YES ☐ NO Mobile number: __________________
DD / MM / YY

PART A: GENERAL INFORMATION

1) Village Name: _________________________________

2) Panchayat Name: ____

3) Number of members in the household (total): _______

4) Complete the following chart for the primary respondent:

Name	Age	Sex	Marital Status 0 = single 1 = married 2 = widowed	Grade Standard Achieved	Literate 0 = illiterate 1 = only write name 2 = read but not write 4 = read and write	Occu-Pation 0 = labour 1 = NREGA 2 = migrant work
(Initial Respondent)						

5. Religion: ☐Hindu ☐Muslim ☐Christian ☐Other

6. Caste: ☐ GC ☐ OBC ☐MBC ☐ SC ☐ST ☐BRAHMIN

7. Economic Status of Household: ☐Above Poverty Line ☐Below Poverty Line ☐Ultra Poor

PART B: HOUSEHOLD ASSETS

1. Do you currently OWN / RENT (circle one) land? ☐ Yes ☐No

   a. If yes, how many acres? _____________ acres

   b. How many acres are under your <u>personal cultivation</u>? ________________ acres

   c. How many acres of land do you lease to other farmers? ________________ acres

d. Do you have functioning irrigation facilities? ☐ Yes ☐ No

a. If yes, how many acres are irrigated? ____________ acres

e. How did you acquire your land?

☐ Inheritance
☐ Purchased
☐ Combination of inheritance and purchased

f. What types of crops do you grow? (check all that apply)

☐ Crops for household consumption: _________ acres
☐ Food crops for local resale (to families/neighbours/local markets): ______________ acres
☐ Commercial crops (sell to intermediary 'merchants'): ______________ acres

2. Do you currently own livestock? ☐ Yes ☐ No

If YES, please indicate the number of livestock you currently have:

Chickens: ____________ Cattle: ______________ Buffalo: ______________

Goats: ______________ Sheep: ______________

Other (please describe): ____________________

3. Do you rent or own your house? ☐ Rent ☐ Own

4. What type of house do you currently live in?

☐ Pucca ☐ Kutcha ☐ Semi-Pucca ☐ Other

5. What is the primary source of drinking water for the household?

☐ Tap ☐ Hand Pump ☐ Bore Well ☐ Open Well ☐ Stream

6. Where is your drinking water located?

☐ In the house ☐ In the village _______ meters away ☐ Outside the village _______ km away

7. On a typical day, how many hours do you have electricity (current)? ____________________ hrs

8. How far away is the closest government health care center? ______________ km

a. Is this a private or a public facility? ☐ Private ☐ Public

9. Do you own a vehicle? ☐ Yes ☐ No

If YES, please identify the type of vehicle:

☐ Two-wheeler ☐ Three-wheeler ☐ Four-wheeler ☐ Bicycle

10. Over the last 1 year, how did your household generate income? (Select all that apply)

☐ Agriculture ☐ Livestock ☐ Local day labour work
☐ NREGA work ☐ Local Shop/Business ☐ Money from outside work (migrant work)
☐ Loans ☐ Local job (e.g. cook, sweeping) ☐ Government scheme
☐ Providing loans to others ☐ Merchant work ☐ Support from relatives
☐ Other (please describe): ______________________________

PART C: Global Physical Activity Questionnaire

1. Do you participate in labour work or any other work requiring physical exercise? ☐ Yes ☐ No

If YES, what type of work do you do? ______________________________

How many hours per day do you work? __________

How many days per week do you work? __________

How many months per year do you work? __________

2. Do you regularly walk long distances (e.g. to go to the market, visit friends in neighbouring villages, etc.) ☐ Yes ☐ No

If YES, how many minutes/hours of walking (on average) per trip? __________ MINUTES / HOURS (circle one)

How many times per week? __________ times

3. Do you regularly ride a bicycle for transportation? ☐ Yes ☐ No

If YES, how many minutes/hours per trip? __________ MINUTES / HOURS (circle one)

How many times per week? __________ times

4. Do you exercise for leisure? (e.g. play sports, walk for health reasons) ☐ Yes ☐ No

If YES, how many hours per week do you partake in these activities? __________ hrs per week

5. Do you own a television? ☐ Yes ☐ No
If YES, how many hours per day do you watch television? __________ hrs/day

PART D: Awareness about type 2 diabetes

1. Do you know what diabetes is? ☐ Yes ☐ No

2. Do you think, in general, more and more people are affected with diabetes nowadays? ☐ Yes ☐ No

3. What are the factors you think contribute to diabetes (NO LEADING QUESTIONS, CHECK ALL THAT APPLY)?

☐Obesity ☐Decreased physical activity ☐Family history of diabetes ☐Mental stress

☐Consuming more sweets ☐ Consuming more rice ☐ Others (name): ____________________

4. Do you think that diabetes can affect other organs? ☐Yes ☐No ☐Don't know

If YES, what are they? 1. ________________ 2. ________________ 3. ________________

5. Can diabetes be prevented? ? ☐Yes ☐No ☐Don't know

PART E: Health seeking behavior

1. When you get sick, where do you go for treatment? ☐ Government Hospital ☐ Private Hospital ☐ Natural/Ayurvedic doctor ☐ Nowhere ☐ Other ________________

2. How often do you seek medical care? (select the one that is most accurate)

☐ Once per week ☐Once per two weeks ☐Once per month
☐Once per two months ☐Once per 6 months ☐Once per year
☐Less than once per year ☐Never

PART E: Anthropometric/Physiology Measurements

1. Body Mass Index measurements: HEIGHT: __________ cm WEIGHT: __________ kg

2. Skin fold measurements:

Triceps: ______mm Biceps: ______mm Subscapular: ______mm Supra-iliac: ______mm

3. Waist circumference: ____________ Hip circumference: ____________

4. Fasting blood glucose: __________ mmol/L X 18 = __________ mg/dL

Post-prandial blood glucose: __________ mmol/L x 18 = __________ mg/dL

5. Hemoglobin level: ____________ g/L

6. HbA1C Score: ____________

PART G: Dietary questions and Food Frequency Questionnaire

1. Has your diet changed appreciably in the past 15 years? ☐ Yes ☐ No

a. If YES, Please tell us how your diet has changed (NOW compared to 15 years ago, CIRCLE ONE FOR EACH):

MORE / LESS fruits and vegetables

MORE/ LESS meat products

MORE / LESS pulses (avarai, thobarai)

MORE / LESS millet products (samai, varagu, thennai, raagi products)

MORE / LESS tea and/or coffee

MORE / LESS sweets and bakery items

2. Do you ever fast? ☐ Yes ☐ No

a. If YES, how many times per year? ________________ times per year

How many days per fast? ____________________ days per fast

3. Are there any times during the year when your household doesn't have enough food? ☐ Yes ☐ No

a. If YES, how many weeks/months does this period last? ____________ WEEKS / MONTHS (circle one)

FFQ GOES HERE

APPENDIX 8: Food frequency questionnaire

Interviewer code: MDRF-DHAN-NTDS-2013-_______________

MDRF-FOOD FREQUENCY QUESTIONNAIRE

Interview ☐☐ ☐☐ ☐☐☐☐ Start!time!of!interview!(12!hr!clock ☐☐ ☐☐ ☐☐

Day Month Year Hrs!!!!!!!!!!Min!!!!am/pm

[Use only blue pen for administration and black pen for second correction]

OPEN ENDED QUESTIONS			
1	How often do you have the following meals outside home? *(Mark the frequency as number of time(s) eaten, tick if "Never" eaten)*	***Break fast*** ***Lunch*** ***Dinner*** Weekly ☐ ☐ ☐ Monthly ☐ ☐ ☐ Never ☐ ☐ ☐	
2	Are you a? *(Tick the appropriate box)*	Lacto vegetarian Non-vegetarian Ova vegetarian Vegetarian	☐ ☐ ☐ ☐
3	Indicate the oils & fat used for cooking *(Mark in the order of usage as1, 2, 3…..)*	Blended oil specify____________ Coconut Corn Ghee Groundnut/peanut Palmolein Rice bran Sesame / Gingelly Sunflower / Safflower Vanaspathi / dalda Others specify___________	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐
4	What kind and type of rice do you usually consume? *(Tick the appropriate box)*	**Kind** Sona /bapatla/ponni Idly rice Basmathi Red Others specify __________	☐ ☐ ☐ ☐

		Type Brown Hand pounded Parboiled Raw Steamed	
5	Do you sieve the wheat flour while preparing chappathis / rotis (flat bread)? ***(Tick the appropriate box)***	Yes No	☐ ☐
6	List the most commonly consumed fish varieties ***(List the varieties)***	1. ________________ 2. ________________ 3. ________________	
7	Do you take any vitamin and / or mineral supplements? ***(Tick the appropriate box)*** If 'Yes', specify	Yes No 1. ________________ 2. ________________ 3. ________________	☐ ☐
8	Do you add water in milk/ coffee/ tea preparation? *If 'Yes', specify the quantity per litre*	Yes ☐ No ☐ Water added _____ml / pkt / l	
9	Do you add salt on table/ while eating? Eg. Curd rice, buttermilk, kanji / left over rice. Please specify the quantity if yes	Yes ☐ No ☐ ______tsp/ pinch per day	

Food code	Food items	Session code	Food measure		Average use last year					
					Frequency of servings					
			Portion tools#	Portion size#	Usual serving size	Never	Daily	Weekly	Monthly	Yearly
	Breakfast									

Interviewer code: **MDRF-DHAN-NTDS-2013-**_______________

1	Aappam	1	No.	S M L						
2	Adai	1	No.	S M L						
5	Bread, white	1	Slice	S M L						
6	Bread, whole / brown	1	Slice	S M L						
7	Chappathi with oil	1	No.	S M L						
8	Chappathi without oil/ phulka	1	No.	S M L						
9	Dosa - all varieties	1	No.	S M L XL						
10	Egg boiled/ bulls eye / omelette	1	No.	S M L						
11	Idiyappam	1	No.	S M L						
12	Idly - all varieties (cereal based)	1	No.	Xs S M L						
13	Medu vada / plain bonda	1	No.	S M L						
14	Noodles - Non veg	1	plate** cup	S M L						
15	Noodles – Veg	1	plate** cup	S M L						
16	Parota (refined wheat flour)	1	No.	S M L						
17	Pongal	1	Tbsp** ldl cup	S M L						
18	Poori - all varieties	1	No.	S M L						
19	Porridge – Cereal Eg. kanji,left over rice	1	G. ldl cup	S M L						
20	Porridge – Millets	1	G. ldl cup	S M L						
21	Puttu – Cereals	1	No. S.ldl cup	S M L						
22	Puttu – millets	1	No. S.ldl cup	S M L						
23	Roti – Millets Eg. Ragi / jowar / bajra	1	No.	S M L						
24	Sandwich - (Plain bread toast)	1	Set	S M L						
25	Sandwich – vegetables	1	Set	S M L						
26	Uppuma/ kichidi/ sevai - cereals	1	Tbsp** S. ldl cup	S M L						

MDRF-.-FOOD-FREQUENCY-QUESTIONNAIRE-(MDRF_FNDR_DHAN_NTDS_2013)-STUDY

**hf,hp,tsp,Tbsp,plate,tp-portion sizes not applicable *# Please refer manual & food atlas for portion size & tools*

Interviewer code: MDRF-DHAN-NTDS-2013-____________

Food code	Food items	Session code	Food measure		Average use last year					
					Frequency of servings					
			Portion tools#	Portion size#	Usual serving size	Never	Daily	Weekly	Monthly	Yearly
	Accompaniment / side dishes									
31	Butter, ghee - as topping	1	tsp** Tbsp**	***						
32	Cheese	1	Slice tsp**	***						
33	chutney powder / idly powder	1	tsp** Tbsp**	***						
34	Chutneys , Greens	1	tsp** Tbsp** ldl	S M L						
35	Chutneys , Vegetable	1	tsp** Tbsp** ldl	S M L						
36	Chutneys, Nuts	1	tsp** Tbsp** ldl	S M L						
37	Coconut milk	1	ldl Cup	S M L						
38	Curd(Plain home made yogurt)	1	Tbsp** ldl Cup	S M L						
39	Honey / sugar / jaggery / jam	1	tsp** Tbsp**	***						
40	Kurma / vegetable subji	1	Tbsp** ldl Cup	S M L						
41	Oil as topping,specify -----------------	1	tsp** Tbsp**	***						
42	Potato masala / subji	1	Tbsp** ldl Cup	S M L						
43	Sambar all varieties	1	Tbsp** ldl Cup	S M L						
44	Vadai curry	1	Tbsp** ldl Cup	S M L						
45	Curry - spicy gravy(no lentils)	1	Tbsp** ldl Cup	S M L						

**hf,hp,tsp,Tbsp,plate,tp-portion sizes not applicable *# Please refer manual & food atlas for portion size & tools*

Interviewer code: **MDRF-DHAN-NTDS-2013-**______________

Food code	Food items	Session code	Food measure		Average use last year					
					Frequency of servings					
			Portion tools#	Portion size#	Usual serving size	Never	Daily	Weekly	Monthly	Yearly
	Lunch									
27	Rice cooked (parboiled)	2	Tbsp** R.ldl Cup	S M L						
28	Rice cooked (raw)	2	Tbsp** R.ldl Cup	S M L						
29	Rice -mixed (lime / tamarind / tomato rice)	2	Tbsp** R.ldl Cup	S M L						
30	Rice- Veg / pulao/ biriyani	2	Tbsp** R.ldl Cup	S M L						
46	Rice- Veg / pulao/ biriyani (basmati)	2	Tbsp** R.ldl Cup	S M L						
47	Rice - plain fried / jeera	2	Tbsp** R.ldl Cup	S M L						
48	Rice- coconut	2	Tbsp** R.ldl Cup	S M L						
49	Sambar rice / bath	2	Tbsp** R.ldl Cup	S M L						
50	Dhal fry	2	Tbsp** ldl Cup	S M L						
51	Sambar lunch (without coconut)	2	Tbsp** ldl Cup	S M L						
236	Sambar lunch (with coconut)	2	Tbsp** ldl Cup	S M L						
45	Curry - spicy gravy(no lentils)	2	Tbsp** ldl Cup	S M L						
52	Legumes - gravy (all varieties)	2	Tbsp** ldl Cup	S M L						
53	Morekuzambu (Spiced yoghurt curry)	2	Tbsp** ldl Cup	S M L						
54	Vadai kofta curry	2	Tbsp** ldl Cup	S M L						
55	Rasam	2	ldl Cup	S M L						
56	Potato -Dry subji	2	Tbsp** ldl Cup	S M L						
57	Roots Stir fried eg. Carrot, beetroot, radish	2	Tbsp** ldl Cup	S M L						
58	Yam, colocasia, sweet potato -Dry subji	2	Tbsp** ldl Cup	S M L						
59	Leafy vegetables stir fried	2	Tbsp** ldl Cup	S M L						
60	Kootu – vegetables	2	Tbsp** ldl Cup	S M L						
61	Kootu Greens	2	Tbsp** ldl Cup	S M L						
62	Aviyal -(mixed veg with coconut)	2	Tbsp** ldl Cup	S M L						
63	Papad / Vadams (fried oil)	2	No. hp* cup	S M L						
64	Papad / Vadams (toasted)	2	No. hp* cup	S M L						
65	Pickle (lime / mango / thokku)	2	tsp** Tbsp**	***						
66	Coconut added in veg preparation	2	tsp** Tbsp**	***						

**hf,hp,tsp,Tbsp,plate,tp-portion sizes not applicable *# Please refer manual & food atlas for portion size & tools*

Interviewer code: **MDRF-DHAN-NTDS-2013-**_____________

Food code	Food items	Session code	Food measure: Portion tools#	Food measure: Portion size#	Average use last year: Usual serving size	Frequency of servings: Never	Daily	Weekly	Monthly	Yearly
67	Dhal added in veg preparation like usilli	2	tsp** Tbsp**	***						
68	Other veg & gourds(brinjal ladiesfinger etc)	2	Tbsp** ldl Cup	S M L						
38	Curd (Plain home made yogurt)	2	Tbsp** ldl Cup	S M L						
69	Legumes- dry preparation	2	Tbsp** ldl Cup	S M L						
70	Buttermilk/ lassi without salt	2	ldl Cup stg	S M L						
71	Salt - added on curd / buttermilk	2	pinch tsp**	***						
72	Salad veg	2	Tbsp** cup plate**	S M L						
234	Raitha cucumber/onion	2	Tbsp** ldl Cup	S M L						
	Non Vegetarian									
73	Chicken – deep fry	3	Piece. ldl Cup	S M L						
74	Chicken - Biryani	3	Plate** R. ldl Cup	S M L						
75	Chicken – masala / gravy	3	Tbsp** ldl Cup	S M L						
76	Chicken kabab/ tandoori	3	No.	S M L						
10	Egg, bulls eye / omelette	3	No.	S M L						
77	Egg curry / masala	3	Tbsp** ldl Cup	S M L						
78	Egg, White - boiled, poached	3	No.	S M L						
79	Egg,Whole boiled / poached	3	No.	S M L						
80	Fish, gravy / masala	3	Tbsp** ldl Cup	S M L						
81	Fish: specify _________ - deep fry	3	No. piece (fillet)	S M L						
82	Dried fish gravy/ curry	3	Tbsp** ldl Cup	S M L						
83	Dried Fish : specify _________ - deep fry	3	Tbsp** Cup	S M L						
84	kidney, liver, brain, intestine – shallow fry	3	Tbsp** piece Cup	S M L						
85	Mutton – shallow fry	3	No. ldl Cup	S M L						
86	Mutton - Biryani	3	plate** R. ldl Cup	S M L						
87	Mutton – masala / gravy	3	Tbsp** ldl Cup	S M L						
88	Mutton – kabab / tandoori	3	No.	S M L						
89	Pork, Beef – gravy / curry	3	ldl Cup	S M L						
90	Pork ,Beef - fry	3	Tbsp** piece Cup	S M L						
91	Pork ,Beef - Biryani	3	plate** R. ldl Cup	S M L						

**hf,hp,tsp,Tbsp,plate,tp-portion sizes not applicable *# Please refer manual & food atlas for portion size & tools*

Interviewer code: **MDRF-DHAN-NTDS-2013-_______________**

Food code	Food items	Session code	Food measure		Average use last year					
						Frequency of servings				
			Portion tools#	Portion size#	Usual serving size	Never	Daily	Weekly	Monthly	Yearly
92	Prawn, oyster, crab - gravy / curry/shallow fry /fry	3	No. ldl Cup	S M L						
	Dinner (items from breakfast/ lunch)									
7	Chappathi with oil	9	No.	S M L						
8	Chappathi without oil/ phulka	9	No.	S M L						
38	Curd (Plain homemade yogurt)	9	Tbsp** ldl Cup	S M L						
45	Curry - spicy gravy(no lentils)	9	Tbsp** ldl Cup	S M L						
9	Dosa - all varieties	9	No.	S M L XL						
12	Idly - all varieties (cereal based)	9	No.	Xs S M L						
63	Papad / Vadams (fried oil)	9	No. hp* cup	S M L						
93	Parota - scrambled	9	plate*	***						
16	Parota (refined wheat flour)	9	No.	S M L						
27	Rice cooked (parboiled)	9	Tbsp** R.ldl Cup	S M L						
28	Rice cooked (raw)	9	Tbsp** R.ldl Cup	S M L						
51	Sambar lunch (without coconut)	9	Tbsp** ldl Cup	S M L						
94	Paneer masala	9	Tbsp** ldl Cup	S M L						
40	Kurma / vegetable subji	9	Tbsp** ldl Cup	S M L						
35	Chutneys , Vegetable	9	Tsp** Tbsp** ldl	S M L						
52	Legumes - gravy (all varieties)	9	Tbsp** ldl Cup	S M L						

**hf,hp,tsp,Tbsp,plate,tp-portion sizes not applicable *# Please refer manual & food atlas for portion size & tools*

Interviewer code: **MDRF-DHAN-NTDS-2013-**____________

Food code	Food items	Session code	Food measure		Average use last year					
					Frequency of servings					
			Portion tools#	Portion size#	Usual serving size	Never	Daily	Weekly	Monthly	Yearly
	Snacks & Fast foods									
95	Almonds	4	No.	***						
96	Bajji(onion)	4	No.	S M L						
97	Masala vada	4	No	S M L						
98	Bajji(potato,plantain) /veg bonda	4	No.	S M L						
99	Bhatura / chola puri	4	No.	S M L						
100	Bhel /sev / dahi poori	4	plate*	***						
101	Burger - Veg (cheese)	4	No.	S M L						
102	Burger – non Veg	4	No.	S M L						
103	Cashewnut - roasted	4	No.	***						
104	Chips -banana / potato / tapioca (fresh)	4	hf** hp** Cup	S M L						
105	Chips processed	4	hf** hp** Cup	S M L						
107	Groundnut roasted	4	hf** hp** Cup	S M L						
108	Groundnut steamed	4	hf** hp** Cup	S M L						
13	Medu vada / plain bonda	4	No.	S M L						
109	Murrukku	4	No. cup	S M L						
113	Pistachio	4	No	***						

**hf,hp,tsp,Tbsp,plate,tp-portion sizes not applicable # *Please refer manual & food atlas for portion size & tools*

Interviewer code: **MDRF-DHAN-NTDS-2013-**________________

Food code	Food items	Session code	Food measure: Portion tools#	Food measure: Portion size#	Average use last year: Usual serving size	Frequency of servings: Never	Daily	Weekly	Monthly	Yearly
116	Plum cakes	4	piece.	S M L						
117	Popcorn / cheese corn puffs	4	cup	S M L XL						
118	Puff - Non veg	4	No.	***						
119	Puff - Veg	4	No.	***						
120	Puffed rice	4	hf** hp** Cup	S M L						
121	Puffed rice - Roasted with masala	4	hf** hp** Cup	S M L						
122	Rice flakes	4	hf** hp** Cup	S M L						
123	Samosa / cutlet - Non veg	4	No.	S M L						
124	Samosa /cutlet /kachori- Veg	4	No.	S M L						
125	Sev (pakoda/ mixture/ boondhi/ ompodi)	4	hf** hp** Cup	S M L						
126	Soup - cream	4	Stg Cup	S M L						
127	Soup – non cream	4	Stg Cup	S M L						
	Bakery & Soft beverages									
128	Aerated : Cola beverages	5	btl G tin	S M L						
129	Aerated : Non-cola drinks(orange,lemonades)	5	btl G tin	S M L						
130	Biscuits - plain	5	No.	S M L						
131	Biscuits - salt	5	No.	S M L						
132	Biscuits - sweet	5	No.	S M L						
133	Bun - cream / jam / butter	5	No.	S M L						
134	Bun - plain	5	No.	S M L						

**hf,hp,tsp,Tbsp,plate,tp-portion sizes not applicable   *# Please refer manual & food atlas for portion size & tools*

Interviewer code: **MDRF-DHAN-NTDS-2013-**___________

Food code	Food items	Session code	Food measure		Average use last year					
					Frequency of servings					
			Portion tools#	Portion size#	Usual serving size	Never	Daily	Weekly	Monthly	Yearly
135	Cake with nuts	5	No.	S M L						
136	Cake-cream / icing	5	No.	S M L						
137	Cake-plain, sponge	5	No.	S M L						
138	Cookies all types	5	No.	S M L						
139	Crackers whole/ multi grains	5	No.	S M L						
141	Synthetic : fruit flavoured drinks (non-aerated)	5	btl G tp**	S M L						
235	Tender coconut water	5	No stg	S M L						
	Milk & its products									
142	Filter Coffee with milk (% of milk ______)	6	Stg mug	S M L						
143	Ice cream - plain	6	cup	S M L						
144	Ice cream - with nuts	6	cup	S M L						
145	Ice cream (cone)	6	cone	S M L						
146	Instant Coffee with milk (% of milk _____)	6	Stg mug	S M L						
147	Malted/ flavoured beverages (Horlicks,milo etc)	6	Stg mug	S M L						
148	Milk < 1.5%(Aavin magenta,skim milk)	6	Stg mug	S M L						
149	Milk -3-4% (Aavin blue,Heritage)	6	Stg mug	S M L						
150	Milk -4 %(Cow's milk)(fresh)	6	Stg mug	S M L						
151	Milk 4.5-5% (Aavin green,Arokya)	6	Stg mug	S M L						
152	Milk -6% (Aavin red)	6	Stg mug	S M L						
153	Milk 6.5% / buffalo's milk	6	Stg mug	S M L						

**hf,hp,tsp,Tbsp,plate,tp-portion sizes not applicable *# Please refer manual & food atlas for portion size & tools*

Interviewer code: **MDRF-DHAN-NTDS-2013-**______________

Food code	Food items	Session code	Food measure		Average use last year					
					Frequency of servings					
			Portion tools#	Portion size#	Usual serving size	Never	Daily	Weekly	Monthly	Yearly
156	Sugar / jaggery – added in beverages	6	tsp** Tbsp**	***						
157	Tea with milk (% of milk __________)	6	Stg mug	S M L						
158	Black coffee / tea	6	Stg mug	S M L						
	Sweets									
159	Adhirasam	7	No.	S M L						
160	Badhusha, suryakala	7	No.	S M L						
162	Biscuits fried, seedai	7	hf** hp* cup	S M L						
163	Burfi – all nuts	7	No.	S M L						
164	Candies	7	No.	S M L						
165	Chikkies all varieties	7	No.	S M L						
166	Chocolates	7	Piece bar	S M L						
167	Halwa all varieties	7	No. Tbsp* cup	S M L						
168	Jamun all varieties	7	No.	S M L						
169	Jangiri	7	No.	S M L						
170	Kaju / badam, pista sweets (soft/ hard)	7	No.	S M L						

**hf,hp,tsp,Tbsp,plate,tp-portion sizes not applicable *# Please refer manual & food atlas for portion size & tools*

Interviewer code: **MDRF-DHAN-NTDS-2013-**______________

Food code	Food items	Session code	Food measure: Portion tools#	Food measure: Portion size#	Average use last year: Usual serving size	Frequency of servings: Never	Daily	Weekly	Monthly	Yearly
171	Kesari	7	Piece. Tbsp** cup	S M L						
172	Kheers / payasam	7	stg cup	S M L						
173	Kozhukattai	7	No.	S M L						
174	Ladoo all varieties	7	No.	S M L						
175	Milk sweets (hard / soft)	7	No. Tbsp* cup	S M L						
176	Mysorepak	7	No	S M L						
177	Poli varieties	7	No.	S M L						
178	Pongal sweet	7	Tbsp* cup	S M L						
179	Rasagulla, chum-chum	7	No	S M L						
180	Somas	7	No	S M L						
181	Sonpapadi all varieties	7	No	S M L						
182	Suviyam, sweet bonda	7	No.	S M L						
	Fruits									
183	Amla (S=12)	8	No.	S M L						
184	Apple (S=12)	8	No. slice cup	S M L						
185	Banana (S=12)	8	No.	S M L						
186	Chikoo / sapota (S=3)	8	No. slice cup	S M L						
187	Custard apple (S=6)	8	No. cup	S M L						
188	Dates, dried (S=12)	8	No. hf** hp*	S M L						

**hf,hp,tsp,Tbsp,plate,tp-portion sizes not applicable *# Please refer manual & food atlas for portion size & tools*

Interviewer code: **MDRF-DHAN-NTDS-2013-**______________

Food code	Food items	Session code	Food measure		Average use last year					
					Frequency of servings					
			Portion tools#	Portion size#	Usual serving size	Never	Daily	Weekly	Monthly	Yearly
189	Fresh fruit milk shake, sweetened	8	G	S M L						
190	Fruit juice – sweetened	8	G tp	S M L						
191	Fruit salad - mixed	8	cup	S M L						
192	Grapes (S=12) (blue/green)	8	hp** hf** cup	S M L						
193	Guava (S=5)	8	No. slice cup	S M L						
194	Jackfruit (S=4)	8	No	S M L						
195	Jambu (S=2)	8	No. hf** hp*	S M L						
196	Mango (S=3)	8	No. slice cup	S M L						
197	Melon (musk / rock)	8	No. slice cup	S M L						
198	Orange(S=12)	8	No. slice cup	S M L						
199	Papaya (S=12)	8	No. slice cup	S M L						
200	Pear (S=0)	8	No. slice cup	S M L						
201	Pineapple(S=4)	8	No. slice cup	S M L						
202	Plums (S=0)	8	No	S M L						
203	Pomegranate (S=12)	8	hp** hf** cup	S M L						
204	Raisins (S=12)	8	No. hf** hp**	***						
205	Strawberry (S=0)	8	No.	S M L						
206	Sweet lime (S=12)	8	No. slice cup	S M L						
207	Water melon (S=3)	8	Slice cup	S M L						
	Alcohol									
208	Beer	10	btl	S M L						
209	Wine	10	peg G	S M L						
210	Spirits-Rum/whisky/brandy	10	peg G	S M L						
211	Country liquors-Toddy	10	ml	S M L						

**hf,hp,tsp,Tbsp,plate,tp-portion sizes not applicable # *Please refer manual & food atlas for portion size & tools*

Interviewer code: MDRF-DHAN-NTDS-2013-________________

End time of Interview (12 hr clock)

Hrs Min am/pm

Abbreviations		
btl - bottle	No. - Number	S.ldl-subji laddle
stg - stainless steel glass	R.ldl - Rice ladle	ldl - Ladle
hf - handful	Tbsp - tablespoon	tp - tetra pack
hp - handpick	tsp - teaspoon	G- glass

Interviewer Name & code :_______________ ☐☐

Quality Checking:-

(Use only red pen)

Supervisor : ________________________

Data keyed by (Name and code) :___________________& ☐☐

Data keyed on : ☐☐ ☐☐ ☐☐☐☐
Day Month Year