Epidemiological Correlates of Overweight and Obesity in the Northern Cape Province, South Africa

Mackenzie H Smith[1], Justin W Myrick[2], Oshiomah Oyageshio[3], Caitlin Uren[4,5], Jamie Saayman[4], Sihaam Boolay[4], Lena van der Westhuizen[2], Cedric Werely[4], Marlo Möller[4,5], Brenna M Henn[2], Austin W Reynolds[1]

Affiliations: [1] Department of Anthropology, Baylor University, Waco, Texas 76706, USA

[2] Department of Anthropology and UC Davis Genome Center, University of California, Davis, CA 95616, USA

[3] Center for Population Biology, University of California, Davis, CA 95616, USA

[4] DSI-NRF Centre of Excellence for Biomedical Tuberculosis Research, South African Medical Research Council Centre for Tuberculosis Research, Division of Molecular Biology and Human Genetics, Faculty of Medicine and Health Sciences, Stellenbosch University, Cape Town, South Africa.

[5] Centre for Bioinformatics and Computational Biology, Stellenbosch University, Stellenbosch, South Africa

Corresponding Author:
Austin W Reynolds[1]
One Bear Place #97173
Waco, TX 76798
Email address: Austin_Reynolds@baylor.edu

Abstract
Background.

In the past several decades, obesity has become a major public health issue worldwide, associated with increased rates of chronic disease and death. Like many developing nations, South Africa is experiencing rapid increases in BMI, and as a result, evidence-based preventive strategies are needed to reduce the increasing burden of overweight and obesity. This study aimed to determine the prevalence and predictors of overweight and obesity among a multi-ethnic cohort from the rural Northern Cape of South Africa.

Methods.

These data were collected as part of a tuberculosis (TB) case-control study, with 395 healthy control participants included in the final analysis. Overweight and obesity were defined according to WHO classification. Multivariate linear models of BMI were generated using sex, age, education level, smoking, alcohol consumption, and diabetes as predictor variables. We also used multivariable logistic regression analysis to assess the relationship of these factors with overweight and obesity.

Results.

The average BMI in our study cohort was 25.2. The prevalence overweight was 18.0% and the prevalence of obesity was 25.0%. We find that female sex, being older, having more years of formal education, having diabetes, and being in a rural area are all positively associated with BMI in our dataset. Women (OR = 5.6, CI = 3.3-9.8), older individuals (OR = 1.02, CI = 1-1.04), and those with more years of education (OR = 1.20, CI = 1.09-1.32) were all more likely to be overweight or obese. Alternatively, being a smoker is negatively associated with BMI and decreases one's odds of being overweight or obese (OR = 0.28, CI = 0.16-0.46).

Conclusions.

We observed a high prevalence of overweight and obesity in this study. The odds of being overweight and obese was higher in women and those with more education and increases with

Commented [JA1]: Please revise as per your new model age. Community-based interventions to control obesity in these communities should pay special attention to these groups.

Commented [JA2]: Same here;

Introduction

Obesity, a medical condition characterized by excessive fat accumulation, can have severe consequences for health, including increased risk of cardiovascular disease, certain cancers, and stroke [1]. ~~Obesity is a particularly important risk factor for type 2 diabetes, which has been implicated in increased diabetes prevalence among many LMICs [2, 3]~~.

Obesity is most commonly determined through the measurement of Body Mass Index (BMI), a metric calculated by dividing an individual's weight in kilograms by their height in meters squared. From 1990 to 2015, global mortality associated with elevated BMI increased by 28.3%, with the majority of these deaths being caused by cardiovascular disease [4]. In addition to its effects on individual health, high obesity incidence can have substantial economic implications, with a global impact of approximately $2.0 trillion annually [5]. The costs linked to obesity range from medical expenses and pharmaceuticals to absenteeism and premature mortality [6].

Commented [JA3]: Combine in one paragraph

Global obesity prevalence increased almost threefold between 1975 and 2016 [7]. A 2015 study showed that 603.7 million adults globally were classified as obese, representing 12.0% of the adult population [4]. Based on current trends, it has been estimated that 1.12 billion adults worldwide will be classified as obese by 2030, and an additional 2.16 billion as overweight [8], roughly 40% of the world population. Sub-Saharan Africa in particular has shown staggering increases in obesity prevalence in the past several decades. Among seven countries in this region in 2009, an average of 31.4% of women were classified as overweight or obese [9]. In Malawi, 18% of men and 44% of women in urban areas were categorized as overweight or obese [10].

Various behavioral contributors to overweight and obesity have been previously identified. Smoking is correlated with lower BMI, and BMI tends to increase after individuals stop smoking [11]. Smoking has also been associated with lower BMI in South African adults [12]. Alcohol consumption has also been linked to BMI outcomes, however whether this correlation is positive or negative has been widely debated in the literature [13]. -Obesity is a particularly important risk factor for type 2 diabetes, which has been implicated in increased diabetes prevalence among many LMICs [2, 3]

Commented [JA4]: I suggest that you explore in this paragraph the well known associated factors with obesity. Becareful about the association with diabetes it can not be predictor but rather associated factor.

In accordance with both global trends and those observed in sub-Saharan Africa, the population of South Africa has also demonstrated a rapid increase in average BMI over the past several years [14–16]. As of 2016, 33% of men and 68% of women in South Africa were categorized as overweight or obese [17]. These values are higher than what has been reported in other African nations [18]. Various behavioral factors have also been studied in South African populations, with several studies indicating an inverse correlation between smoking and BMI [12, 19]. There is also evidence for higher obesity incidence among women as compared to men in South Africa, a trend often observed in developing nations [8, 18, 20].

It is important to note, however, that the majority of research on BMI and obesity in South Africa has been conducted on urban cohorts, particularly in the Eastern and Western Cape Provinces [21, 22]. Although national statistics on measures of obesity are available that are representative of both urban and rural communities in South Africa [17], these are reported at the provincial level as part of the South Africa Demographic and Health Survey (DHS). As part of the most recent DHS only 177 residents of the Northern Cape from across the province were sampled for measures of body mass index (68 men and 109 women) [17]. As a result, the variation in overweight and obesity across rural and peri-urban South African districts and municipalities, such as those in the Northern Cape Province, remains limited, restricting our understanding of how overweight and obesity manifest in these communities. This gap in the literature is important given the observed differences in obesity trends between urban and rural communities in lower- and middle-income nations [23]. In South Africa specifically, women in urban areas were 1.6 times more likely, and urban men 2.3 times more likely, to have excessive BMI than those in rural areas [20]. However, the average BMI of both men and women is increasing much more rapidly among rural communities than urban communities globally [24]. Further investigation in these smaller communities is crucial in identifying risk factors and working towards improved public health initiatives and education.

In this study, we analyze some of the demographic and behavioral factors related to BMI in the Northern Cape of South Africa. Our sample consists of 395 individuals from rural areas, small towns, and one large municipality in the province. Investigating these factors will give us a more fine-grained understanding of obesity across the region and lay the groundwork for the development of specialized public health and education initiatives to reduce the prevalence of obesity and overweight among this region.

Materials & Methods

Study Design and Sampling Procedure

The data used in this study was collected as part of the Northern Cape Tuberculosis (NCTB) Project, a case-control study on host susceptibility to TB. Between 2017 and the beginning of the SARS-CoV-2 pandemic in 2020, data was collected on 1,095 individuals (N_{men} = 544; N_{women} = 551) recruited from 12 community (public) health clinics in the Northern Cape Province, South Africa that serve populations with high TB rates, mostly in rural towns with populations under 10,000. The Northern Cape Province has the largest area, lowest population size and lowest population density in South Africa [50]. Data was collected via participant interviews, medical histories, saliva samples, and anthropometric measurements. Patients ≥18 years and older evaluated for TB were invited to participate. In this study, only participants with a negative TB result were included due to a symptomatic effect of TB on BMI [25]. Controls are patients presenting with TB-like symptoms and/or TB contacts who had a negative GeneXpert Ultra sputum result. Community healthcare clinics are the front-line for medical care and triage, and often the sole healthcare facility. The sampling strategy was purposively designed for TB cases and controls not for BMI (i.e., convenience sample), however, this sample retains some heterogeneity in controls as most members of the population seek medical care from the community healthcare clinics and because TB exposure is community-wide [52-56] anyone meeting the minimum criteria for TB evaluation is tested.

Participants were partitioned into the case or control group based on a decision tree considering previous TB diagnosis, treatment for TB, and TB test results obtained during the course of the study (Oyageshio, in prep.). Because TB was much more common among men than women in our study (Oyageshio, in prep.), our final sample of 395 healthy controls included substantially more women than men (n_{male} = 145; n_{female} = 250).

Ethics and Informed Consent

Data collected from study participants was approved by the Health Research Ethics Committee of Stellenbosch University (Project number: N11/07/210A) and the Institutional Review Board of the University of California, Davis (IRB number: 1749073-1). Participation in this study was voluntary, with the ability to withdraw at any time. Written informed consent was obtained and subsequent medical and demographic questionnaires were conducted in the local language of Afrikaans by trained research assistants from the community. All data was kept confidential with no connections to participant names. Deidentified variables were stored in a secure RedCap database following data collection.

Demographic and Socio-economic Factors

Demographic information was collected through interviews and recorded on a data collection sheet. Participants were asked to provide their town of residence, highest level of education achieved, and the ethnic group with which they self-identify.

Medical History

During interviews, participants self-reported diabetes, HIV, asthma, and TB status. If participants reported having diabetes, they were asked to identify if they were a type 1 or type 2 diabetic. HIV status was self-reported as positive, negative, or unknown. Asthma was recorded as no, yes, or unknown. In addition to asking participants whether they had TB at the time of the study, they were also asked if they were currently taking TB medication, whether they had TB in the past, and if so, how many TB episodes they had experienced. Following the self-reporting of TB information, TB tests were administered to all participants using GeneXpert, Auramine O Stain, GeneXpert Ultra, SMEAR, or Culture tests.

Behavioral Factors

Alcohol use was evaluated by asking participants if they drink alcohol. If yes, further information was collected regarding the specifics of their alcohol consumption. Participants were asked whether they drink beer, wine, liquor, or ginger beer, and how much of each they consume during the week and weekend. Smoking behavior was categorized as yes or no. If participants answered yes to smoking, they were asked to provide the age at which they began smoking, as well as the average amount they smoke per day.

Anthropometry

Height was measured using a Charder HM200P stadiometer. Participants were asked to look straight ahead and stand with their heels against the wall while measurements were being taken. One height measurement was recorded for participants in pilot data collection and two measurements were taken upon initiation of the primary study. For individuals with two recorded measurements for height, the average of these values was used. Weight was measured with a Seca 876 digital scale and recorded once. Height and weight measurements were used to calculate BMI for each participant using the equation: BMI = kg/m^2. Waist and hip circumference measurements were taken with the guidance of a research assistant using a measuring tape, following WHO measurement guidelines [49]. Briefly, the participant was asked to hold one end of a flexible measuring tape near the navel or side of the hips. The research assistant then pulled the measuring tape around the circumference of the waist or hips, ensuring that the widest point was being measured, asking the participant to hold the remainder of the tape while the measurement was recorded. The measurement was then repeated for a total of two measurements at each location. Shoes, hats, and bulky outer clothing were all removed by participants before the measure of anthropometric variables. Anthropometric variables were collected by community research assistants trained by the researchers. The collection procedures of all research assistants are evaluated every 3-6 months to ensure continued accuracy of the measurements and consistently across research assistants. Following calculation of BMI,

Commented [JA5]: You don't have to put the details of the measurement; important facts is you followed the WHO standard, same researcher that was trained and checked participants were assigned to weight categories based on the guidelines set forth by the Centers for Disease Control and Prevention: those with a BMI < 18.5 were classified as “Underweight”, 18.5 to <25 as “Healthy,” 25 to <30 as “Overweight,” and 30 or higher as “Obese” [26]. Waist-to-hip ratio was calculated by dividing average waist circumference (cm) by average hip circumference (cm).

Quality Control

Participants who were TB positive, HIV positive, or both (N = 642), were removed from this study due to an expected effect of disease on BMI. All hip and waist measurements supervised by community health care worker #5 were also removed due to errors in measurement technique, where waist and hip circumferences were not being measured at the widest point. BMI could not be calculated for an additional 18 participants due to an absence of height measurements, weight measurements, or both, and these individuals were removed. A total of 395 individuals were included in BMI analyses, 206 of which were recruited during pilot data collection. The addition of WHR measurements and additional questions about smoking and drinking behavior (types and amounts of alcohol/tobacco consumed daily) were added to the collection protocol after the pilot phase. As a result, these additional behavioral variables were not included in the BMI model, and our sample sizes for the WHR measurements are much lower than that of the overall BMI analysis (**Table 1**).

Statistical Analyses

Quality control and data analysis were performed in R 4.0.2. The packages effects [27, 28] was used for data analysis, and ggplot2 [29] was used for data visualization.

Six covariates (alcohol intake (yes or no), smoking (yes or no), diabetes (yes or no), sex, age, and years of education) were entered into a generalized linear model to further characterize their association with BMI. As observed in other studies, BMI was not normally distributed among our sample, therefore we used log-transformed BMI as the outcome variable. Bivariate effect plots were generated between BMI and each individual covariate included in the model. Additional generalized linear models were generated by partitioning male and female participants to examine sex-specific effects.

Commented [JA6]: Please update as per your new model

Commented [JA7]: It seems you did not do adjusted models but rather you did the model for each group of gender. Make sure to reflect that in table 3. Stratifying the sample and doing analysis on each part is different than adjusted model

We also performed statistical analyses using waist-to-hip ratio (WHR) in place of BMI. A generalized linear model was created using WHR as the outcome variable and included alcohol intake, smoking, diabetes, sex, years of education, and age. This model included 161 participants. Bivariate effect plots were created between WHR and alcohol intake, smoking, diabetes, sex, age, and highest qualification. Our generalized linear models were supplemented by the generation of odds ratios using the *questionr* package [30] to investigate the relationship between individual variables and BMI outcome (overweight/obese versus not).

Results

Participant Demographics

Our final sample (**Table 1**) included 395 participants (n_{male} = 145; n_{female} = 250). The mea n age was 44 years ± 15, with all participants falling between 18 and 86 years of age. Our dataset was collected across twelve study sites, representing rural areas (n=158), small towns (n=106), and one small city (n=131) from the Northern Cape Province, South Africa. The most common self-identified ethnicity among participants was Coloured (87%, people of indigenous Khoe-San, Bantu-speaking African, European, Southeast Asian and East Asian ancestry) [51], followed by Nama (4%) and Tswana (3%) (**Table S1**). Approximately 7% of participants

Commented [JA8]: Table 1 is still missing appropriate formatting of numbers, means and standard deviation with a decimal point. The n for the percentages in some variables. Add the rural areas to the table.

reported having no education, 27% reported attending or completing primary school, and 66% reported attending or completing secondary school.

Behavioral Factors

The majority (62%) of participants were smokers. Among women, 54% reported that they smoked, compared to 75% of men. Only 39% of participants reported consuming some quantity of alcohol. This also differed by sex, with 50% of men and 34% of women in our sample reporting alcohol consumption.

Anthropometry and BMI

Mean height and weight were 159cm ± 10 (range: 109.4-184.9cm) and 63kg ± 19 (range: 27-134kg) respectively. The mean BMI was 25.2 ± 8.0. Nearly a quarter (22%) of participants were classified as underweight, 35% as healthy, 18% as overweight, and 25% as obese. The distribution of individuals between these classifications differed substantially between male and female participants, with 36% of female participants being placed in the obese category compared to only 5% of male participants (**Table 1**).

Factors associated with BMI, WHR, and obesity

We fit a generalized linear model to investigate the relationship between BMI and the factors of sex, age, education, smoking, drinking, diabetes status, and clinic type. This model showed significant relationships between BMI and smoking, sex, education level, age, diabetes, and rural clinics (**Table 2**). Together, these factors explained 27 % of the variance in BMI among our cohort, with an F-value of 26.54 (p<0.001). Being female showed a strong positive correlation with BMI, as did age, years of education, and rural clinic type. The

Commented [JA9]: Again missing the decimal point (also in the standard deviation

Commented [JA10]: It seems clinic type was entered as two variables. Please indicate in the method section about that? Usually there is a reference value

Commented [JA11]: I don't see the difference or the needs of table 2 as compared to table 3. Unless you want the table 3 to be related to gender differences relationships between each of these variables and BMI were observed in our bivariate effect plots (**Figure S1**), which indicated a 5-point BMI increase for women, a 4-point decrease for smoking, a 6-point increase for having 14 years of education as compared to zero, and a 4-point increase for rural clinic locations as compared to large towns

We find evidence that women in our sample had over 5 times greater odds of being overweight or obese compared to men (OR = 5.56, CI = 3.3-9.8; **Table 3**). In our dataset, every one-year increase in age is associated with a 2% increase in the odds of being overweight or obese, while each additional year of school completed increased those odds by 20 %. Smoking, on the other hand, showed a significant negative correlation with BMI ($p < 0.001$). In fact, smoking decreased the odds of being overweight or obese by nearly 75% in our study population (OR = 0.28, CI = 0.16-0.46). Rural clinic type was associated with 3 times greater odds of being overweight or obese (OR = 3.29, CI = 1.85-5.97). Additionally, the odds of being overweight or obese were more than 4 times greater in participants with type 2 diabetes.

We also explored the factors associated with waist-to-hip measurement ratios in our dataset. This model was fit on a subset of the dataset (**Table S1**; n=160), as waist and hip measurements were not available for all participants. We find a slight positive correlation between WHR and years of education ($p = 0.03$), but together these variables only explain ~1 % of the variance in WHR in our dataset with an F-value of 1.15 ($p = 0.33$). No other covariates showed a significant association with WHR.

Commented [JA12]: Please revise table 3 to include the ODDs ratios and proper write up of the pvalue. Please don't copy paste from the statistical software.

Commented [JA13]:

Please make sure to highlight the odds ratios with significant P values.

Discussion

In this study we analyzed the demographic and socio-behavioral factors related to BMI in an adult cohort from the Northern Cape Province, South Africa. Our results suggest a significant difference in obesity trends between men and women in the study population. Sex-based differences were observed not only in obesity incidence, but also in the degree to which various factors impact BMI outcomes. While smoking has a strong negative correlation with BMI in both men and women, we find that age and years of education are only significantly correlated with BMI in women. Although we had significantly more female participants (250 women, 145 men), our results are consistent with previous research. Higher obesity incidence among women as compared to men is observed in other studies on South African populations [14, 19–20]. While data regarding the effect of socioeconomic status on BMI outcomes in males and females shows variability depending on the metric used to represent socioeconomic status, Wagner et al. found that primary and tertiary education were associated with greater BMI values in females only [19]. Interestingly, while we find an association between age and BMI among females only, previous research has demonstrated this correlation for males only [12, 20].

Two sampling limitations for this study include limited waist-to-hip ratio (WHR) data and convenience sampling. BMI is a simple and widely used metric for obesity, however, it does not distinguish between excess fat, muscle, or bone mass, or provide any indication of the distribution of fat among individuals [31, 32], whereas WHR is better at predicting visceral adiposity and cardiometabolic disease risk [33, 34]. Future work incorporating these and other more sensitive measures of adiposity will provide greater detail into the risk-factors and consequences of obesity in this population.

The sampling strategy for this study was purposively designed to maximize TB cases and controls, not necessarily for maximizing heterogeneity of BMI in the population. Given this limitation, our controls are fairly evenly distributed across important variables such as age, education, height, and weight. Additionally, because TB exposure is community-wide, reaching

Commented [JA14]: Leave the limitation section to the end

~90% by age 30 [52-56], TB nurses and healthcare staff test anyone meeting the minimum criteria for TB evaluation; and because these community healthcare clinics are typically the only accessible facility, it is seen by all members of the community. While this sample includes more heterogeneity than a typical convenience sample, it does not fully assuage biases, such as higher SES patients who opt for out-of-area private medical clinics or selection biases in who decided to seek medical attention, among others.

In line with prior research on sex differences in BMI and obesity, we find 57% of female participants were overweight or obese compared to only 19% of male participants. One such study found that in 5 out of 6 sampling locations in sub-Saharan Africa, a higher percentage of females were categorized as obese as compared to males [35]. A study in Soweto, South Africa showed that the proportion of women classified as obese was twice that of men [12]. There are several potential explanations for the extreme obesity risk associated with being female in our sample population. Past research has shown that higher BMI is desirable in many African countries, as it is representative of wealth, health (particularly absence of HIV), and fertility [36-41]. It has also been shown that having control over household food spending is associated with greater incidence of obesity in women [36].

Previous work has shown that socioeconomic status, including educational level, is positively correlated with BMI, for both men and women, in South Africa [35, 42, 43], as well as other low- and middle-income nations [35, 44]. This aligns with our result demonstrating the more education one has, the higher their BMI – each year of education increases their odds of being overweight or obese by 18%. This trend may be explained by cultural factors, as being overweight or obese reflects wealth in low-income communities where many lack adequate access to food. A study on 37 lower- and middle-income nations showed that BMI was positively associated with wealth in all 37 countries surveyed [45]. Previous work has also found that a person's daily amount of vigorous physical activity also decreases with increasing wealth [46, 47], suggesting a multifactorial relationship between socioeconomic status and BMI. Interestingly, we do not see a significant relationship between age and years of education in our model of men-only. This pattern has been reported elsewhere [36] and suggest that other factors may be more important in explaining BMI variation in men in the Northern Cape.

Our results indicating that smoking decreases odds of being overweight or obese by 75% are also in line with previous research. Nicotine use suppresses appetite and causes an increased resting metabolic rate, resulting in weight loss [48]. Smoking has previously been associated with lower BMI in South African adults [12, 31].

Comparing our results to the 2016 South Africa Demographic and Health Survey [17] provincial data for the Northern Cape, we find similar levels of overweight and obesity for women (57% and 62%, respectively). However, we find substantially fewer overweight and obese men (18% versus 32%) and substantially more underweight men in our sample compared to the province as a whole (39% versus 19%). Interestingly, our findings demonstrate greater odds of being overweight or obese in rural regions than in large towns. While previous data in South Africa has found that men and women in urban areas were more likely to have excessive BMI than those in rural areas, research has also shown that the average BMI of both men and women is increasing much more rapidly among rural communities than urban communities globally [24]. Province-wide measurements from the SADHS, show no substantial differences in BMI between urban and rural samples, demonstrating the regional variability in obesity and reinforcing the need to collect more data at the district and municipality level to better understand the demographic and social factors that may be influencing obesity on a local scale.

Commented [JA15]: It is advised to have a story telling in this section. As it is now written, just facts in sentences. Try to link between the sentences

Conclusions

Overall, our results suggest that smoking, sex, education level, age, location, and diabetes all influence BMI outcomes among the rural population of the Northern Cape of South Africa, consistent with previous research in other South African cohorts and developing nations. These results deepen our understanding of the factors contributing to obesity risk in this region. The present study was limited somewhat by the behavioral data collected as part of the larger TB study. A necessary future direction of this work will be to include additional measures of adiposity, physical activity and dietary behaviors, and socio-economic status to obtain a more complete understanding of the risk-factors for obesity in the Northern Cape. This will allow for better identification of high-risk groups for behavioral interventions, ultimately mitigating the public health and economic burdens created by the global obesity epidemic at the local level.

Acknowledgements

First and foremost, we would like to thank our participant communities in the Northern Cape for their continued trust and support in helping us undertake this project. We would also like to thank our community research assistants and translators who assisted in data collection for the project. Finally, we want to thank the Department of Health in the Northern Cape Province, South Africa for their continued support of the project.

References

1. CDC. Adult Obesity Facts. 2021.

2. Barceló A, Gregg E.W., Pastor-Valero M, Robles, S. C. Waist circumference, BMI and the prevalence of self-reported diabetes among the elderly of the United States and six cities of Latin America and the Caribbean. Diabetes Research and Clinical Practice 2007;78:418–427.

3. Teufel F, Seiglie J.A., Geldsetzer P et al. Body-mass index and diabetes risk in 57 low-income and middle-income countries: a cross-sectional study of nationally representative, individual-level data in 685 616 adults. The Lancet 2021;398:238–248.

4. The GBD 2015 Obesity Collaborators. Health Effects of Overweight and Obesity in 195 Countries over 25 Years. N Engl J Med. 2017;377:13–27.

5. Dobbs R, Sawers C, Thompson F, Manyika J, Woetzel J, Child P, et al. Overcoming obesity: An initial economic analysis. 2014.

6. Dee A, Kearns K, O'Neill C, Sharp L, Staines A, O'Dwyer V, et al. The direct and indirect costs of both overweight and obesity: a systematic review. BMC Res Notes. 2014;7:242.

7. WHO. Obesity and Overweight Factsheet. 2021.

8. Popkin BM, Adair LS, Ng SW. Global nutrition transition and the pandemic of obesity in developing countries. Nutrition Reviews. 2012;70:3–21.

9. Ziraba AK, Fotso JC, Ochako R. Overweight and obesity in urban Africa: A problem of the rich or the poor? BMC Public Health. 2009;9:465.

10. Price AJ, Crampin AC, Amberbir A, Kayuni-Chihana N, Musicha C, Tafatatha T, et al. Prevalence of obesity, hypertension, and diabetes, and cascade of care in sub-Saharan Africa: a cross-sectional, population-based study in rural and urban Malawi. The Lancet Diabetes & Endocrinology. 2018;6:208–22.

11. Piirtola M, Jelenkovic A, Latvala A, Sund R, Honda C, Inui F, Watanabe M, Tomizawa R, Iwatani Y, Ordoñana J.R., et al. Association of current and former smoking with body mass index: A study of smoking discordant twin pairs from 21 twin cohorts. PLoS ONE 2018;13:e0200140.

12. Micklesfield LK, Kagura J, Munthali R, Crowther NJ, Jaff N, Gradidge P, et al. Demographic, socio-economic and behavioural correlates of BMI in middle-aged black men and women from urban Johannesburg, South Africa. Global Health Action. 2018;11:1448250.

13. Sayon-Orea C, Martinez-Gonzalez M.A., Bes-Rastrollo M. Alcohol consumption and body weight: a systematic review. Nutrition Reviews 2011;69:419-431.

14. Cois A, Day C. Obesity trends and risk factors in the South African adult population. BMC Obes. 2015;2:42.

15. Steyn K, Fourie J, Rossouw JE, Langenhoven ML, Joubert G, Chalton DO. Anthropometric profile of the coloured population of the Cape Peninsula. 1990;78:5.

16. Steyn K, Bourne L, Jooste P, Fourie J, Rossouw K, Lombard C. Anthropometric profile of a black population of the Cape Peninsula in South Africa. East African Medical Journal. 1998;75:35–40.

17. Statistics South Africa, South Africa, editors. South Africa Demographic and Health Survey 2016. Key indicators report. Pretoria: Statistics South Africa; 2017.

18. Goedecke J, Jennings C, Lambert E. Obesity in South Africa. Chronic Diseases of Lifestyle in South Africa: 1995-2005. 2006;:65–79.

19. Wagner RG, Crowther NJ, Gómez-Olivé FX, Kabudula C, Kahn K, Mhembere M, et al. Sociodemographic, socioeconomic, clinical and behavioural predictors of body mass index vary by sex in rural South African adults-findings from the AWI-Gen study. Global Health Action. 2018;11:1549436.

20. Okop KJ, Levitt N, Puoane T. Factors Associated with Excessive Body Fat in Men and Women: Cross-Sectional Data from Black South Africans Living in a Rural Community and an Urban Township. PLoS ONE. 2015;10:e0140153.

21. Malhotra R, Hoyo C, Østbye T, Hughes G, Schwartz D, Tsolekile L, et al. Determinants of obesity in an urban township of South Africa. South African Journal of Clinical Nutrition. 2008;21:315–20.

22. Owolabi EO, Ter Goon D, Adeniyi OV. Central obesity and normal-weight central obesity among adults attending healthcare facilities in Buffalo City Metropolitan Municipality, South Africa: a cross-sectional study. J Health Popul Nutr. 2017;36:54.

23. Neuman M, Kawachi I, Gortmaker S, Subramanian SV. Urban-rural differences in BMI in low- and middle-income countries: the role of socioeconomic status. The American Journal of Clinical Nutrition. 2013;97:428–36.

24. NCD Risk Factor Collaboration (NCD-RisC). Rising rural body-mass index is the main driver of the global obesity epidemic in adults. Nature. 2019;569:260–4.

25. Zhang H, Li X, Xin H, Li H, Li M, Lu W, et al. Association of Body Mass Index with the Tuberculosis Infection: a Population-based Study among 17796 Adults in Rural China. Sci Rep. 2017;7:41933.

26. CDC. Defining Adult Overweight and Obesity. 2021.

27. Fox J. Effect Displays in R for Generalised Linear Models.pdf. Journal of Statistical Software. 2003;8.

28. Fox J, Weisberg S. An R Companion to Applied Regression. 3rd Edition. Thousand Oaks, CA: Sage; 2019.

29. Wickham H. ggplot2: Elegant Graphics for Data Analysis. New York, NY: Springer; 2016.

30. Barnier J, Briatte F, Larmarange J. questionr: Functions to Make Surveys Processing Easier. 2022.

31. Rothman KJ. BMI-related errors in the measurement of obesity. Int J Obes. 2008;32:S56–9.

32. Adab P, Pallan M, Whincup PH. Is BMI the best measure of obesity? BMJ. 2018;:k1274.

33. Song X, Jousilahti P, Stehouwer CDA, Söderberg S, Onat A, Laatikainen T, et al. Comparison of various surrogate obesity indicators as predictors of cardiovascular mortality in four European populations. Eur J Clin Nutr. 2013;67:1298–302.

34. Lee CMY, Huxley RR, Wildman RP, Woodward M. Indices of abdominal obesity are better discriminators of cardiovascular risk factors than BMI: a meta-analysis. Journal of Clinical Epidemiology. 2008;61:646–53.

35. Ramsay M, Crowther NJ, Agongo G, Ali SA, Asiki G, Boua RP, et al. Regional and sex-specific variation in BMI distribution in four sub-Saharan African countries: The H3Africa AWI-Gen study. Global Health Action. 2018;11:1556561.

36. Case A, Menendez A. Sex differences in obesity rates in poor countries: Evidence from South Africa. Economics & Human Biology. 2009;7:271–82.

37. Naigaga D.A., Jahanlu D, Claudius, H.M. et al. Body size perceptions and preferences favor overweight in adult Saharawi refugees. Nutrition Journal 2018;17:17.

38. Okop KJ, Mukumbang FC, Mathole T, Levitt N, Puoane T. Perceptions of body size, obesity threat and the willingness to lose weight among black South African adults: a qualitative study. BMC Public Health. 2016;16:365.

39. Puoane T, Tsolekile L, Steyn N. Perceptions about body image and sizes among Black African girls living in Cape Town. Ethnicity & Disease 2010;20:29-34.

40. Renzaho AM. Fat, rich and beautiful: changing socio-cultural paradigms associated with obesity risk, nutritional status and refugee children from sub-Saharan Africa. Health Place. 2004;10:105–13.

41. T. Matoti-Mvalo RD(SA), MPH & T. Puoane B (Cur), MPH, Dr PH. Perceptions of body size and its association with HIV/AIDS. South African Journal of Clinical Nutrition 2011;24:40-45

42. Alaba O, Chola L. Socioeconomic Inequalities in Adult Obesity Prevalence in South Africa: A Decomposition Analysis. IJERPH. 2014;11:3387–406.

43. Wandai ME, Aagaard-Hansen J, Manda SO, Norris SA. Transitions between body mass index categories, South Africa. Bull World Health Organ. 2020;98:878-885I.

44. Dinsa GD, Goryakin Y, Fumagalli E, Suhrcke M. Obesity and socioeconomic status in developing countries: a systematic review. Obesity Reviews. 2012;13:1067–79.

45. Neuman M, Finlay JE, Davey Smith G, Subramanian S. The poor stay thinner: stable socioeconomic gradients in BMI among women in lower- and middle-income countries. The American Journal of Clinical Nutrition. 2011;94:1348–57.

46. Gradidge PJ-L, Norris SA, Munthali R, Crowther NJ. Influence of socioeconomic status on changes in body size and physical activity in ageing black South African women. Eur Rev Aging Phys Act. 2018;15:6.

47. Micklesfield LK, Pedro TM, Kahn K, Kinsman J, Pettifor JM, Tollman S, et al. Physical activity and sedentary behavior among adolescents in rural South Africa: levels, patterns and correlates. BMC Public Health. 2014;14:40.

48. Audrain-McGovern J, Benowitz NL. Cigarette Smoking, Nicotine, and Body Weight. Clin Pharmacol Ther. 2011;90:164–8.

49. WHO. Waist circumference and waist–hip ratio: report of a WHO expert consultation, Geneva. 2008.

50. Statistics South Africa. Mid-year population estimates. Pretoria. 2022: P0302.

51. Swart Y, Uren C, van Helden P, Hoal E and Möller M. Local Ancestry Adjusted Allelic Association Analysis Robustly Captures Tuberculosis Susceptibility Loci. Front. Genet. 2021; 12:716558.

52. Andrews JR, Morrow C, Walensky RP, Wood R. Integrating social contact and environmental data in evaluating tuberculosis transmission in a South African township. J Infect Dis. 2014;210(4):597-603. doi:10.1093/infdis/jiu138

53. Gallant CJ, Cobat A, Simkin L, et al. Impact of age and sex on mycobacterial immunity in an area of high tuberculosis incidence. Int J Tuberc Lung Dis. 2010;14(8):952-959.

54. Mahomed H. The incidence of tuberculosis in adolescents in the context of proposed TB vaccine trial. Univ Cape Town. Published online 2013. https://open.uct.ac.za/bitstream/handle/11427/9314/thesis_hsf_2013_mohamed_h.pdf?sequence=1&isAllowed=y

55. Mahomed H, Ehrlich R, Hawkridge T, et al. TB incidence in an adolescent cohort in South Africa. PLoS One. 2013;8(3):e59652. doi:10.1371/journal.pone.0059652

56. Mahomed H, Ehrlich R, Hawkridge T, et al. Screening for TB in high school adolescents in a high burden setting in South Africa. Tuberc Edinb. 2013;93(3):357-362. doi:10.1016/j.tube.2013.02.007