Background

Sub-Saharan Africa is undergoing major demographic and epidemiological transitions marked by an ageing population, persisting communicable diseases such as HIV and tuberculosis and increasing non-communicable diseases (NCDs) such as hypertension and diabetes [1–3]. Over the past 25 years, the levels of overweight and obesity, measured respectively as a body mass index (BMI) ≥ 25 kg/m² and 30 kg/m², have increased by more than 330%, contributing to the growing burden of NCDs on the continent [4]. Elevated BMI is an important risk factor for a number of NCDs including cardiovascular diseases, type 2 diabetes (T2D), musculoskeletal conditions and certain cancers.

In South Africa, it has been suggested that obesity is responsible for at least 78% of cases of T2D, 68% of cases of hypertension, 45% cases of ischemic strokes and 38% of cases of ischemic heart disease [5].

The prevalence of obesity on the African continent is heterogeneous with southern Africa, a region comprising Botswana, Lesotho, Namibia, South Africa, Swaziland and Namibia, having the highest levels [6]. South Africa has one of the highest levels on the continent, with 7.6% of males and 36.8% of females over the age of 15 years estimated to be obese (in this age group, 41.3% and 68.5% of males and females respectively, are considered to be overweight or
obese) [7]. These figures vary significantly both by ethnic group and by sex, with the latter not seen in high-income countries [8].

While sex appears to be a strong biological risk factor for excess weight [7], it is likely to be the interplay between this and sociodemographic, socioeconomic, clinical and behavioural determinants, including diet, history of alcohol use and sedentary lifestyle, that ultimately results in increased BMI. These determinants may therefore represent modifiable risk factors for obesity in high prevalence areas such as South Africa. While previous studies in South Africa have explored the prevalence and determinants of elevated BMI in younger individuals and urban dwellers [9,10], there are relatively few data on BMI among adults in rural areas [11–13], where a significant proportion of the population resides. Health services in these areas are limited, highlighting the need to intervene in at-risk individuals before NCDs develop.

In this study, we aimed to identify the risk factors for increased BMI, a key determinant for NCDs, in a rural South African adult population in the midst of demographic and epidemiological transitions. Given existing evidence that suggests sex is a strong determinant of obesity, we investigated these risk factors both overall and in subgroups defined by sex. These factors may represent targets for context-specific interventions aimed at halting and ultimately reducing overweight and obesity.

Methods

Study site

This study forms part of the multi-site Africa Wits-INDEPTH partnership for Genomic Studies (AWI-Gen), which took place in 6 sites across 4 sub-Saharan African countries, including two sites in rural South Africa. The data presented in this paper were obtained from the Agincourt Health and Socio-Demographic Surveillance System (HDSS), one of the rural South African sites [14–16]. The Agincourt HDSS comprises 450 km² and 31 research villages and is located 500 km northeast of Johannesburg in rural Mpumalanga. Since 1992, the Agincourt HDSS, managed by the MRC/Wits Rural Public Health and Health Transitions Research Unit, has annually enumerated the entire population to capture vital events, including births, migrations and deaths. In 2015, the population of the HDSS was 120,000 individuals residing in approximately 20,000 households.

Participant selection

All individuals aged 40 years or older as of 1 July 2014 who were documented in the 2013 census as permanently residing in the study site, were eligible to participate in this study.

Individuals who had previously participated in earlier studies investigating the interaction between HIV and NCDs [17,18] were invited to participate and, to supplement this group, a random sample of individuals aged 40–60 years was drawn from the 2013 Agincourt HDSS database. The sample was stratified by sex to achieve equal numbers of males and females. Participants were a subset of those who had been enrolled in Health and Ageing in Africa: a Longitudinal Study of an INDEPTH Community in South Africa (HAALSI) [19]. Of the 2000 individuals selected for recruitment, 1465 agreed to participate. This paper is based on the 1388 (94.7%) individuals on whom complete data on all study variables were available. The 77 individuals excluded due to missing data did not differ significantly by age, sex or BMI.

Study procedures

Study visits took place between March 2015 and May 2016. All selected participants were visited at home by trained fieldworkers and invited to participate in the study. Informed consent was sought and, when provided, study participants were invited to come to the Agincourt HDSS laboratory on a pre-specified date. At the laboratory, a fieldworker administered a computer-aided personal interview (CAPI) which solicited sociodemographic, socioeconomic, behavioural and clinical data. Participants also underwent a series of tests and measurements, including height and weight. These were measured by trained research staff using a Harpenden digital stadiometer (Holtain Ltd, Crymych, Wales) and a digital Genesis Growth Management Scale (Genesis Pharmaceuticals, Johannesburg, South Africa), respectively. All participants who took part in the study at the Agincourt HDSS laboratory were given a coffee mug as a token of appreciation at the conclusion of their visit.

Variable derivation

Outcome variable

BMI was calculated by dividing the mass (in kilograms) of the individual by the square of their height (in metres).

Exposure variables

Sociodemographic, socioeconomic, clinical and behavioural variables were selected based on evidence from existing studies as well as factors such as carbohydrate intake that might be expected to influence BMI.

Sociodemographic variables

Age was calculated at the date of the study visit using the reported date of birth. Marital status was
determined by self-report: individuals were asked to report whether they were currently married or cohabitating, previously married or cohabitating or had never married nor cohabitated, with those who had never married nor cohabitated used as the reference group in regression analyses. Educational attainment was also self-reported with participants indicating their highest completed level of education from a selection of no formal education, primary education and tertiary education. No formal education was used as the reference category in regression analyses.

**Socioeconomic variables**

Employment status was self-reported. Individuals who were self-employed, full-time or part-time employed by someone else or informally employed were classified as employed; unemployed individuals were used as the reference category in regression analyses. Socioeconomic status (SES) quintiles were derived from self-reported household assets using principal components analysis. This method, widely used in HDSSs, constructs a household wealth index based on the type of material of which the main dwelling is built, type of ablution facilities, water and energy sources and ownership of livestock and modern assets. This wealth index can then be used as a proxy for SES [20,21]. The lowest quintile was used as the reference group in analyses.

**Clinical variables**

Individuals were classified as HIV-positive, HIV-negative or of indeterminate HIV status. They were defined as being HIV-positive if they reported being previously diagnosed with HIV or tested positive at the time of enrolment in the associated HAALSI study (determined by Vironostika Uniform 11 [Biomerieux, France] screening assay), HIV-negative if they reported previously having tested negative or tested negative at the time of enrolment in HAALSI and indeterminate if they were unaware of their status and declined a test at the time of enrolment; anti-retroviral therapy use was self-reported. HIV-negative participants were used as the reference group in analyses. Three blood pressure measurements, two minutes apart, were taken on each participant. The mean of the second and third measurements was calculated and hypertension was defined as a mean blood pressure reading \( \geq 140/90 \text{ mmHg} \) at the time of the interview or a previous history of hypertension.

**Behavioural variables**

The CAGE criteria [22] were used to classify alcohol intake. This questionnaire is used to screen for alcohol dependence and may therefore be a useful proxy to quantify alcohol intake. Participants were classified as having no alcohol consumption, current non-problematic consumption or current problematic consumption, with those reporting no consumption used as the reference group. Individuals were classified as never smokers if they reported never having smoked tobacco products, former smokers if they had previously smoked tobacco products and current smokers if they smoked tobacco products at all, regardless of the frequency. Those who reported never having smoked were used as the reference group. Data on food intake were collected, including questions on consumption of carbohydrates such as juice, sugary beverages and bread, all of which could theoretically affect BMI. To ensure consistency in the estimation of food intake, participants were shown sample cards illustrating different food and beverage quantities and asked to identify, to the nearest whole number, the quantity they regularly consumed. The definitions of servings of fruit and vegetable and the quantity of drink consumed can be found in Supplementary Table 1. Total moderate-vigorous physical activity (MVPA) was calculated by summing the self-reported moderate and physical activity involved in occupation-, travel- and leisure-related activities to determine the total minutes of MVPA per week.

Data were imported into the Research Electronic Data Capture system (RedCap) [23].

**Statistical analysis**

Continuous variables were reported using medians and interquartile ranges (IQR) and categorical variables were reported using percentages. Mann Whitney U tests were used to compare continuous variables in subgroups defined by sex, while the chi-square test was used to compare categorical variables in these subgroups. The Kruskal-Wallis test was used to compare BMI between subgroups defined by HIV status. Given the significant sex differences in some variables, further analyses were stratified by sex.

Univariate associations between BMI and individual continuous and categorical variables were investigated using linear regression. Scatter plots were used to investigate extreme values which, in the case of independent variables, were replaced with the median value.

**Multiple linear regression models**

We fitted a series of regression models in which the relationship between sex and BMI was adjusted sequentially for several individual sociodemographic, socioeconomic, clinical and behavioural factors, which differed between males and females, to investigate whether any of these attenuated the effect of sex. A sex-adjusted multiple regression model in the entire sample and models stratified by sex were then
fitted to establish factors associated with BMI. Independent variables with a p-value < 0.2 in univariate analyses were included in the multiple regression models. Dietary factors were also included in multiple regression models, even if they did not attain this level of significance, given their theoretical importance. BMI was log-transformed prior to linear regression analyses to improve normality and regression coefficients were exponentiated prior to reporting. For categorical variables, the exponentiated coefficients indicated percentage change in BMI for the category of interest compared to the reference category while for continuous variables, the exponentiated coefficient indicated the change in BMI for a unit change in the explanatory variable. P- values < 0.05 were considered statistically significant. Analyses were performed using STATA version 14.2 (StataCorp, College Station, TX, USA).

**Ethical considerations**

All participants in this study provided written, informed consent. This study was approved by the Human Research Ethics Committee (Medical) of the University of the Witwatersrand (clearance numbers: M121029; M170880) and the Research and Ethics Committee of the Mpumalanga Province Department of Health.

**Results**

Approximately 61% of our sample was female with a median age of 51 years; over 60% were also unemployed (Table 1). There were significant differences between females and males in the distributions of marital status, education status, socioeconomic quintiles, smoking status and alcohol consumption and females were significantly heavier (p < 0.001). Consumption of bread, vegetables and juice also differed between sexes. More than one-third of the sample was HIV-positive, but the prevalence did not differ significantly between males and females. BMI was significantly lower overall in participants with HIV (p < 0.001) and in both females (p < 0.001) and males (p = 0.001) with HIV (Table 1). A significantly greater proportion of females had hypertension, while

| Table 1. Sociodemographic, socioeconomic, clinical and characteristics of Agincourt adults. |
|---------------------------------------------------------------|
| **Age (years)** | Overall (n = 1388) | Females (n = 846) | Males (n = 542) | p-value |
|---------------------------------------------------------------|
| 51 (46–56) | 51.5 (46–56) | 51 (45–56) | < 0.001 |
| **Marital status** | | | | |
| Never married or cohabitating (%) | 124 (8.9) | 55 (6.5) | 69 (12.7) | < 0.001 |
| Currently married or cohabitating (%) | 938 (67.6) | 514 (60.8) | 424 (78.2) | |
| Divorced/widowed (%) | 326 (23.5) | 277 (32.7) | 49 (9.0) | |
| **Education status** | | | | |
| No formal education (%) | 382 (27.5) | 265 (31.3) | 117 (21.6) | < 0.001 |
| Primary education (%) | 544 (39.2) | 327 (38.6) | 217 (40.0) | |
| Secondary education (%) | 379 (27.3) | 210 (24.8) | 169 (31.2) | |
| Tertiary education (%) | 83 (6.0) | 44 (5.2) | 39 (7.2) | |
| Unemployed (%) | 881 (63.5) | 549 (64.9) | 332 (61.2) | 0.17 |
| **SES quintile** | | | | |
| 1st quintile (%) | 212 (15.3) | 101 (11.9) | 111 (20.5) | < 0.001 |
| 2nd quintile (%) | 330 (23.8) | 188 (22.2) | 142 (26.2) | |
| 3rd quintile (%) | 175 (12.6) | 109 (12.9) | 66 (12.2) | |
| 4th quintile (%) | 326 (23.5) | 203 (24.0) | 123 (22.7) | |
| 5th quintile (%) | 345 (24.9) | 245 (29.0) | 100 (18.4) | |
| **Body mass index (BMI) (kg/m²)** | 26.1 (22.1–31.3) | 28.7 (24.2–33.2) | 23.0 (20.3–26.8) | < 0.001 |
| **HIV seropositive (%)** | 485 (34.9) | 301 (35.6) | 184 (34.0) | 0.788 |
| **BMI (HIV positive) (kg/m²)** | 24.4 (21.1–28.6) | 26.3 (23.0–31.1) | 22.2 (19.8–25.1) | |
| **BMI (HIV negative) (kg/m²)** | 27.3 (25.4–34.0) | 30.1 (25.4–34.0) | 23.8 (20.7–27.8) | |
| **Current anti-retroviral therapy use (%)** | 255 (18.4) | 154 (18.2) | 101 (18.6) | 0.058 |
| **Smoking status** | | | | |
| Never smoker (%) | 1118 (80.6) | 837 (98.9) | 281 (51.8) | < 0.001 |
| Current smoker (%) | 145 (10.4) | 2 (0.2) | 143 (26.4) | |
| Former smoker (%) | 125 (9.0) | 7 (0.8) | 118 (21.8) | |
| **Alcohol consumption** | | | | |
| No history of consumption (%) | 879 (63.3) | 698 (82.5) | 181 (33.4) | < 0.001 |
| Current non-problematic consumption (%) | 247 (17.8) | 49 (5.8) | 198 (36.5) | |
| Current problematic consumption (%) | 19 (1.4) | 2 (0.2) | 17 (3.1) | |
| Former consumption (%) | 243 (17.5) | 97 (11.5) | 146 (26.9) | |
| Bread consumption (slices/week) | 16 (8–28) | 16 (9–28) | 16 (6–28) | 0.034 |
| Vegetable consumption (servings/week) | 4 (2–8) | 5 (3–8) | 4 (2–6) | 0.001 |
| Fruit consumption (servings/week) | 3 (1–6) | 3 (0–6) | 3 (1–6) | 0.383 |
| Sugary beverage intake (drinks/week) | 2 (1–3) | 2 (1–3) | 2 (1–2) | 0.439 |
| Juice intake (days/week) | 1 (0–2) | 1 (0–2) | 1 (0–2) | 0.013 |
| MVPA (minutes/week) | 630 (200–1410) | 600 (200–1380) | 720 (200–1440) | 0.391 |
| Sleep (hours/day) | 8.9 (8.0–9.7) | 8.9 (8.0–9.6) | 9 (8–10) | 0.408 |
| Self-reported diabetes (%) | 52 (3.8) | 32 (3.8) | 20 (3.7) | 0.929 |
| Hypertension (%) | 737 (53.1) | 493 (58.3) | 244 (45.0) | < 0.001 |

Continuous variables are described as medians and interquartile ranges. Mann Whitney U test used to compare continuous variables; chi-square test used to compare categorical variables. Kruskal-Wallis test used to compare BMI between subgroups defined by HIV status. MVPA-moderate to vigorous physical activity, SES-socioeconomic status.
self-reported diabetes, another condition which may result from excess weight, had a low overall prevalence and did not differ between sexes.

In univariate analyses (Table 2), marital status, education status and socioeconomic status were associated with increases in BMI. The highest percentage increases in BMI were associated with being divorced or widowed (16%) and being in the highest socioeconomic quintile (15%). Despite statistically significant associations between higher BMI and consumption of bread, vegetables, fruit, sugary beverages and juice, the changes in BMI with unit increases in these dietary variables were negligible. Current smoking and current problematic alcohol consumption were associated with 14% and 15% reduction in BMI respectively, while HIV-positivity was associated with an 8% reduction in BMI and the use of anti-retroviral therapy was associated with a 12% reduction in BMI. In analyses stratified by sex, being currently married, having tertiary education and having higher socioeconomic status were associated with increased BMI in both sexes, while being HIV-positive, being a former smoker and current problematic alcohol intake were associated with lower BMI in both sexes.

There was a strong association between sex and BMI. Being male was associated with a 17% reduction in BMI and the strength of this relationship was not attenuated by adjustment for any of a series of sociodemographic, socioeconomic, clinical or behavioural characteristics (Table 3).

In multiple linear regression models, several sociodemographic, socioeconomic, clinical and behavioural factors independently predicted BMI, with differing patterns in females and males (Table 4). In an overall model adjusted for sex, BMI was 7% higher in those who were currently or previously married when compared to those who had never been married, while being in the 4th and 5th socioeconomic quintiles was associated with a 5% and 6% increase in BMI respectively. In contrast, being HIV-positive was associated with a 6% reduction in BMI when compared to HIV-negative individuals, while current smoking and former smoking were associated with 14% and 5% reductions in BMI respectively. While bread consumption was statistically associated with an increased BMI, consumption of a single

### Table 2. Linear regressions showing univariate associations between body mass index and sociodemographic, socioeconomic, clinical and behavioural characteristics in Agincourt adults.

| Variable | Overall (n = 1388) | Females (n = 846) | Males (n = 542) |
|----------|-------------------|------------------|-----------------|
|          | exp (B) | 95% CI | p-value | exp (B) | 95% CI | p-value | exp (B) | 95% CI | p-value |
| Age      | 1.00    | 1.00–1.00 | 0.075   | 1.00    | 1.00–1.00 | 0.091   | 1.00    | 1.00–1.00 | 0.472   |
| Marital status |            |          |        |            |          |        |            |          |        |
| Never married or cohabitated | ref | ref | ref | ref | ref |         | ref | ref | ref |
| Currently married or cohabitating | 1.12 | 1.07–1.17 | < 0.001 | 1.09 | 1.03–1.16 | 0.005 | 1.11 | 1.05–1.17 | < 0.001 |
| Divorced/widowed | 1.16 | 1.10–1.21 | < 0.001 | 1.08 | 1.01–1.15 | 0.018 | 1.02 | 0.94–0.99 | 0.659 |
| Education status |            |          |        |            |          |        |            |          |        |
| No formal education | ref | ref | ref | ref | ref |         | ref | ref | ref |
| Primary education | 1.00 | 0.97–1.03 | 0.856   | 1.05 | 1.01–1.09 | 0.012 | 0.96 | 0.92–1.00 | 0.072 |
| Secondary education | 1.00 | 0.97–1.03 | 0.907   | 1.04 | 1.00–1.08 | 0.084 | 1.00 | 0.95–1.05 | 0.939 |
| Tertiary education | 1.07 | 1.01–1.13 | 0.023   | 1.10 | 1.03–1.18 | 0.007 | 1.08 | 1.01–1.17 | 0.034 |
| Employment status |            |          |        |            |          |        |            |          |        |
| Unemployed | ref | ref | ref | ref | ref |         | ref | ref | ref |
| Employed | 1.02 | 0.99–1.04 | 0.215   | 1.01 | 0.97–1.04 | 0.743 | 1.05 | 1.02–1.09 | 0.005 |
| SES quintile |            |          |        |            |          |        |            |          |        |
| 1st quintile | ref | ref | ref | ref | ref |         | ref | ref | ref |
| 2nd quintile | 1.02 | 0.98–1.06 | 0.451   | 0.99 | 0.94–1.05 | 0.765 | 1.00 | 0.95–1.05 | 0.960 |
| 3rd quintile | 1.07 | 1.03–1.12 | 0.002   | 1.04 | 0.98–1.10 | 0.254 | 1.05 | 0.99–1.12 | 0.090 |
| 4th quintile | 1.09 | 1.05–1.14 | < 0.001 | 1.05 | 1.00–1.11 | 0.062 | 1.08 | 1.02–1.13 | 0.005 |
| 5th quintile | 1.15 | 1.10–1.19 | < 0.001 | 1.07 | 1.02–1.13 | 0.009 | 1.15 | 1.09–1.22 | < 0.001 |
| HIV seropositive | 0.92 | 0.89–0.94 | < 0.001 | 0.90 | 0.87–0.93 | < 0.001 | 0.94 | 0.90–0.97 | < 0.001 |
| Current anti-retroviral therapy use | 0.88 | 0.80–0.97 | 0.008   | 0.95 | 0.86–1.05 | 0.301 | 0.77 | 0.63–0.94 | 0.010 |
| Smoking status |            |          |        |            |          |        |            |          |        |
| Never smoker | ref | ref | ref | ref | ref |         | ref | ref | ref |
| Current smoker | 0.76 | 0.73–0.78 | < 0.001 | 1.14 | 0.84–1.55 | 0.402 | 0.83 | 0.80–0.86 | < 0.001 |
| Former smoker | 0.86 | 0.82–0.89 | < 0.001 | 0.71 | 0.60–0.83 | < 0.001 | 0.96 | 0.92–1.00 | 0.037 |
| Alcohol consumption |            |          |        |            |          |        |            |          |        |
| No history of consumption | ref | ref | ref | ref | ref |         | ref | ref | ref |
| Current non-problematic consumption | 0.83 | 0.80–0.86 | < 0.001 | 0.94 | 0.88–1.00 | 0.061 | 0.90 | 0.86–0.93 | < 0.001 |
| Current problematic consumption | 0.75 | 0.68–0.83 | < 0.001 | 0.71 | 0.52–0.96 | 0.028 | 0.85 | 0.77–0.93 | 0.001 |
| Former consumption | 0.92 | 0.89–0.95 | < 0.001 | 0.97 | 0.93–1.02 | 0.222 | 0.97 | 0.93–1.02 | 0.236 |
| Bread consumption | 1.00 | 1.00–1.00 | < 0.001 | 1.00 | 1.00–1.00 | 0.014 | 1.00 | 1.00–1.00 | < 0.001 |
| Vegetable consumption | 1.00 | 1.00–1.01 | 0.013   | 1.00 | 1.00–1.01 | 0.111 | 1.00 | 1.00–1.00 | 0.927 |
| Fruit consumption | 1.00 | 1.00–1.01 | 0.005   | 1.00 | 1.00–1.01 | 0.062 | 1.01 | 1.00–1.02 | 0.002 |
| Sugary beverage intake | 1.01 | 1.00–1.02 | < 0.001 | 1.01 | 1.00–1.02 | 0.013 | 1.01 | 1.00–1.02 | 0.007 |
| Juice intake | 1.01 | 1.00–1.01 | 0.010   | 1.00 | 1.00–1.01 | 0.268 | 1.00 | 1.00–1.01 | 0.307 |
| MVPA | 1.00 | 1.00–1.00 | 0.585   | 1.00 | 1.00–1.00 | 0.805 | 1.00 | 1.00–1.00 | 0.833 |
| Sleep | 0.99 | 0.98–1.00 | 0.004   | 1.00 | 0.99–1.01 | 0.685 | 0.98 | 0.97–0.99 | < 0.001 |

Exp (B)- exponentiated regression coefficient; coefficient interpreted as percentage change in BMI for category of interest vs reference category for categorical variables and percentage change in BMI for unit change of independent variable for continuous variables; MVPA- Moderate to Vigorous Physical Activity; SES-socioeconomic status
Table 3. Linear regressions showing association between sex and body mass index in Agincourt adults, adjusted for individual sociodemographic, socioeconomic, clinical and behavioural characteristics.

| Variable                       | exp (B) | 95% CI | p-value |
|--------------------------------|---------|--------|---------|
| Age                            | 1.00    | 1.00–1.00 | 0.161 | 1.00 | 1.00–1.01 | 0.078 | 1.00 | 1.00–1.00 | 0.743 |
| Marital status                 |         |         |         |
| Never married or cohabitated   | ref     | –       | –       | ref  | –       | –       | ref  | –       | –       |
| Currently married or cohabitating | 1.07   | 1.03–1.11 | 0.001 | 1.06 | 1.00–1.13 | 0.042 | 1.07 | 1.02–1.12 | 0.008 |
| Divorced/widowed               | 1.07    | 1.02–1.12 | 0.003 | 1.08 | 1.01–1.15 | 0.016 | 1.03 | 0.96–1.10 | 0.434 |
| Education status               |         |         |         |
| No formal education            | ref     | –       | –       | ref  | –       | –       | ref  | –       | –       |
| Primary education              | 1.01    | 0.98–1.04 | 0.526 | 1.04 | 1.00–1.08 | 0.027 | 0.96 | 0.92–1.00 | 0.056 |
| Secondary education            | 1.02    | 0.99–1.05 | 0.259 | 1.04 | 1.00–1.09 | 0.062 | 0.97 | 0.93–1.02 | 0.207 |
| Tertiary education             | 1.04    | 0.98–1.09 | 0.164 | 1.08 | 1.00–1.16 | 0.042 | 0.98 | 0.91–1.05 | 0.579 |
| Employment status              |         |         |         |
| Unemployed                     | ref     | –       | –       | –     | –       | –       | ref  | –       | –       |
| Employed                       | 1.01    | 0.98–1.03 | 0.625 | 1.02 | 0.98–1.05 | 0.277 |
| SES quintile                   |         |         |         |
| 1st quintile                   | ref     | –       | –       | ref  | –       | –       | ref  | –       | –       |
| 2nd quintile                   | 1.00    | 0.96–1.03 | 0.942 | 1.00 | 0.95–1.05 | 0.951 | 1.00 | 0.95–1.04 | 0.873 |
| 3rd quintile                   | 1.03    | 0.99–1.08 | 0.109 | 1.03 | 0.98–1.10 | 0.255 | 1.03 | 0.97–1.09 | 0.281 |
| 4th quintile                   | 1.05    | 1.01–1.09 | 0.008 | 1.04 | 0.99–1.10 | 0.131 | 1.06 | 1.01–1.11 | 0.021 |
| 5th quintile                   | 1.06    | 1.02–1.10 | 0.002 | 1.03 | 0.98–1.09 | 0.228 | 1.10 | 1.04–1.15 | 0.001 |
| HIV-positive                   | 0.94    | 0.91–0.97 < 0.001 | 0.91 | 0.88–0.95 < 0.001 | 0.97 | 0.93–1.01 | 0.162 |
| Current anti-retroviral therapy use | 0.94 | 0.86–1.02 | 0.141 | 0.96 | 0.88–1.06 | 0.463 | 0.84 | 0.70–1.01 | 0.063 |
| Smoking status                 |         |         |         |
| Never smoker                   | ref     | –       | –       | ref  | –       | –       | ref  | –       | –       |
| Current smoker                 | 0.86    | 0.83–0.90 < 0.001 | 1.17 | 0.87–1.58 | 0.295 | 0.87 | 0.83–0.91 < 0.001 |
| Former smoker                  | 0.95    | 0.91–0.99 | 0.017 | 0.74 | 0.63–0.87 < 0.001 | 0.97 | 0.92–1.01 | 0.123 |
| Alcohol consumption            |         |         |         |
| No history of consumption      | ref     | –       | –       | ref  | –       | –       | ref  | –       | –       |
| Current non-problematic consume | 0.97 | 0.94–1.01 | 0.143 | 0.98 | 0.92–1.04 | 0.511 | 0.97 | 0.93–1.02 | 0.238 |
| Current problematic consumption | 0.92 | 0.83–1.01 | 0.083 | 0.70 | 0.52–0.94 | 0.019 | 0.96 | 0.87–1.06 | 0.412 |
| Former consumption             | 0.99    | 0.96–1.03 | 0.692 | 0.99 | 0.95–1.04 | 0.654 | 1.00 | 0.96–1.05 | 0.983 |
| Bread consumption              | 1.00    | 1.00–1.00 | 0.024 | 1.00 | 1.00–1.00 | 0.189 | 1.00 | 1.00–1.00 | 0.109 |
| Vegetable consumption          | 1.00    | 1.00–1.00 | 0.323 | 1.00 | 1.00–1.00 | 0.049 | 1.00 | 0.99–1.00 | 0.373 |
| Fruit consumption              | 1.00    | 1.00–1.00 | 0.409 | 1.00 | 1.00–1.00 | 0.749 | 1.00 | 1.00–1.00 | 0.360 |
| Sugary beverage intake         | 1.01    | 1.00–1.02 | 0.052 | 1.01 | 1.00–1.02 | 0.039 | 1.00 | 1.00–1.01 | 0.294 |
| Juice intake                   | 1.00    | 0.99–1.00 | 0.786 | 1.00 | 0.99–1.01 | 0.993 | 0.99 | 0.99–1.00 | 0.242 |
| MVPA                           | 1.00    | 1.00–1.00 | 0.591 | 1.00 | 1.00–1.00 | 0.606 | 1.00 | 1.00–1.00 | 0.976 |
| Sleep                          | 1.00    | 0.99–1.01 | 0.694 | –     | –       | –       | 0.99 | 0.98–1.00 | 0.245 |

Discussion

In this study, we highlight the strong association of female sex with higher BMI in South African adults (7%). Smoking status was also associated with BMI in both sexes. Females who were former smokers had a reduction in BMI of 26% compared to those who had never smoked (p < 0.001) while current male smokers had a reduction in BMI of 13% (p < 0.001).

The effects of other independent variables were confined to either females or males. Primary and tertiary education were associated with higher BMIs (4% and 8% respectively) in females while females with HIV had a 9% lower BMI, independent of antiretroviral drug use, and females with current problematic drinking had a 30% reduction in BMI. Sugary beverage and vegetable intake were statistically associated with a higher BMI in females, but the BMI change with unit increases in consumption of these was negligible. The effect of socioeconomic status was seen only in males, with those in the 4th and 5th quintiles having a higher BMI (6% and 10% respectively) than those in the 1st quintile.
in a rural area. We illustrate that sociodemographic, socioeconomic, clinical and behavioural factors associated with BMI differ in females and males, with being currently or formerly married and having a tertiary education predicting the greatest increase in BMI in females and being in the highest socioeconomic quintile predicting the greatest increase in men.

Our study is in keeping with other work that has reported higher BMI in females. Previous studies in this rural population have reported higher BMIs in females, with an age-adjusted prevalence of obesity of 26% in females aged 15 and older compared to 7% in similarly aged males [17] and a 24.6% higher prevalence of obesity in females in those over 50 years [18]. Similar differences were evident in rural Ghana where the prevalence of obesity in women was seven times that in men [24]. The sex disparity in obesity appears independent of urbanicity with females in rural and peri-urban Uganda being 4.3 times as likely to be obese as males [25] and the prevalence of obesity in females 20–75 years of age in urban Cameroon being 4 times that of their male counterparts [26]. This female preponderance of obesity may be due to several factors including female perceptions of ‘ideal’ body weight, differential effects of childhood undernutrition and adult socioeconomic status [27], although in our study, socioeconomic status did not attenuate the relationship between sex and BMI.

We identified two factors that were associated with BMI in both sexes, namely marital status and smoking status. Our study supports previous research across multiple countries that reported currently married individuals have a higher BMI than their unmarried counterparts [28–30], although the relationship between a higher BMI and being married appears less robust in females. The reasons for this are not entirely clear but may relate to higher household income and ability to afford food. Our finding of increased BMI in previously married females however contrasts with other work which reported either no association or decreased weight, particularly in widowed females [28,31]. The association of decreased weight with widowhood in females is independent of age and changes in eating patterns relating to solitude may be responsible [32]. Societies in rural South Africa, in contrast to the high-income countries in which these studies were conducted, may provide for more mechanisms of social support after the death of a partner, reducing the effects of widowhood on eating patterns. Additionally, we categorised divorced and widowed females together in our study due to sample size and these transitions in marital status may have differing effects on BMI.

We found tobacco use to be inversely related to BMI, with former female smokers and current male smokers having a lower weight than those who had never smoked. Our findings are consistent with a large study in the UK which found that current smokers were 17% less likely to be obese than non-smokers [33]. Former smokers were overall more likely to be obese, but those former smokers who had smoked fewer cigarettes were less likely to be obese suggesting, as the study authors note, that there may be subgroup differences that were not evident in overall associations.

There were predictors of BMI that were restricted to either females or males. Higher educational attainment independently predicted increased BMI in female participants and higher socioeconomic status independently predicted increased BMI in males. The effect of both of these predictors on BMI appears to depend on the wealth and education status in the broader society. Higher BMI is often seen in the wealthier and better-educated in low and middle-income countries as evidenced by studies in peri-urban and rural Uganda and urban Nigeria and national South African studies [25,34,35]. In contrast, in high income countries, obesity appears to be more prevalent in poorer, less-educated individuals [36,37]. This may be due to several factors including the ability of wealthier individuals to afford larger quantities of food and perceptions in some communities in emerging economies that obesity is a desirable characteristic and indicative of personal wealth [38,39].

Being HIV-positive was also associated with lower BMI in females. Furthermore, the median BMI in HIV-positive females, while in the range for a normal BMI, was significantly lower than the median BMI in HIV-negative females. This association was independent of antiretroviral therapy use, suggesting that even when treated, individuals with HIV do not attain the weight of the background population. Several factors may contribute, including inadequate treatment. Use of antiretroviral therapy was self-reported in this study and we did not obtain measures of treatment adequacy. Additionally, more frequent contact with the health care system due to chronic HIV care may provide opportunities for reinforcement of health care messages on the importance of maintaining a healthy weight [40]. Finally, different antiretroviral therapies may also have differing effects on weight [41]. Lower BMI with problematic alcohol consumption may be due to the chronic malnutrition that can occur with excess alcohol intake [42].

While the associations between some dietary factors and BMI were statistically significant, the change in BMI was negligible suggesting that several units of change in these explanatory variables would be necessary to see significant changes in BMI. This contrasts with a study in another rural/peri-urban community in the Eastern Cape of South Africa where frequent
consumption of fast food and fruit and low intake of vegetables were associated with increased risk of obesity [11]. Several factors may explain the absence of strong associations between dietary factors and BMI in our study. We did not, for example, assess consumption of dairy, animal protein, fast food or oils and fats, all of which may be related to BMI. Consumption of bread, juice and sugary beverages was also relatively low, suggesting that there may be other carbohydrate sources that contribute more significantly to the diet in this population and may therefore have a greater influence on weight. The study in the Eastern Cape included adults between 21 and 70 years and dietary influences on obesity may differ over such a broad age range; additionally, the quantification of intake associated with the broad categories of dietary intake of ‘never’, ‘sometimes’ and ‘always’ used in that study were unclear, making direct comparison with our study difficult.

Limitations

This study provides important data on factors associated with BMI in rural South Africa. It does, however, have several limitations. Firstly, our participants were recruited from an HDSS and had been participants in previous studies of NCDs. While these previous studies were observational, participants with suspected hypertension were referred to local clinics. As such, their previous knowledge of their elevated blood pressure or attendance at clinics may have resulted in behavioural modification, making these participants less representative of the general, rural South African population. This limitation was somewhat mitigated by including a new, random sample of participants aged 40 to 60 years. We also performed a complete case analysis, but age, sex and BMI did not differ between the 94.7% of our respondents included in the analysis and those excluded. Thirdly, many of the behavioural exposure variables were self-reported and may therefore have been prone to recall or reporting bias. Some of our exposure variables may also have been too insensitive to identify subgroup effects— for example, the number of female smokers in our sample was quite small which may have resulted in an inability to detect an association between BMI and current smoking in women. We also did not quantify smoking and so were unable to investigate a relationship between the degree of smoking and BMI. We also defined alcohol consumption broadly and did not consider in detail the types and quantities of alcohol consumed; given the different caloric content of alcoholic beverages, a more precise determination of alcohol intake may have revealed other associations between alcohol intake and BMI. We also confined our analysis to the association between BMI and selected sociodemographic, socioeconomic, clinical and behavioural factors. There are likely several other exposure variables in this population that both directly influence BMI and confound the association between BMI and other factors and these were not investigated in this study. Our dietary variables, for example, were very broadly defined. A more precise determination of macronutrient composition may have allowed us to explore relationships between diet and BMI in more detail. Additionally, as HIV testing took place 1 day to 8 months prior to the study visit, some participants may have sero-converted and become HIV-positive in the intervening period. Given the cross-sectional nature of this study, we are unable to draw causal inferences. Future waves of data collection are planned in this cohort of individuals, which will allow better understanding of the causal relationship between BMI and sociodemographic, socioeconomic, clinical and behavioural determinants in females and males.

Our study sample was not nationally representative and the results are therefore not likely to be generalisable to the rest of the South African population. It does however share characteristics with other communities in rural South Africa which are undergoing epidemiological transition, including prevailing high mortality from HIV/AIDS and emerging increasing mortality from non-communicable diseases [21,43] and risk factors for obesity in this study may well be similar in these populations.

Conclusion

This study has confirmed previous work in rural African populations identifying sex as a major determinant of obesity and identifies associations between BMI and sociodemographic, socioeconomic, clinical and behavioural factors that vary by sex. Other factors, such as being married, were associated with higher BMI in both sexes. While future longitudinal studies will assist in confirming the associations found in this study, public health interventions targeted at altering perceptions around the desirability of obesity in this and similar rural African communities and those aimed at married couples may impact weight in these populations.

Acknowledgments

The authors would like to acknowledge the study participants, fieldworkers and administrative staff and the contribution of Dr Sulaimon Afolabi to an earlier version of this manuscript. We would also like to acknowledge the support of the AWI-Gen secretariat, particularly Prof. Michele Ramsay and Dr Stuart Ali.

Author contributions

RGW, NJC, FXGO, KK, ST and ANW contributed to the design of the study. RGW, MM and ZM contributed to the acquisition of the data. ANW and RGW contributed to the analysis and interpretation of data. RGW and ANW
drafted the manuscript. All authors critically revised the manuscript and provided final approval of the version to be published. All authors agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Disclosure statement

No potential conflict of interest was reported by the authors.

Ethics and consent

Approval for this study was granted by the Human Research Ethics Committee (Medical) of the University of the Witwatersrand (M121029; M170880) and the Research and Ethics Committee of the Mpumalanga Province Department of Health.

Funding information

The AWI-Gen Collaborative Centre is funded by the National Human Genome Research Institute (NHGRI), Office of the Director (OD), the Eunice Kennedy Shriver National Institute of Child Health & Human Development (NICHD), the National Institute of Environmental Health Sciences (NIEHS), the Office of AIDS Research (OAR) and the National Institute of Diabetes and Digestive and Kidney Diseases (NIDDK), of the National Institutes of Health (NIH) under award number U54HG006938 and its supplements, as part of the H3Africa Consortium as well as by the Department of Science and Technology, South Africa, award number DST/CON 0056/2014, and by the African Partnership for Chronic Disease Research (APCDR).

The Agincourt HDSS is supported by the Wellcome Trust, UK (058893/Z/99/A, 069683/Z/02/Z, 085477/Z/08/Z and 085477/B/08/Z), the University of the Witwatersrand and the South African Medical Research Council.

Data for this study were collected in conjunction with Health and Ageing in Africa - a Longitudinal Study in an INDEPTH community (HAALSI). HAALSI is funded by the National Institute on Ageing (P01 AG041710) and is supported by the Fogarty International Centre of the National Institutes of Health (USA), the South African Department of Science and Technology or the National Research Foundation (South Africa) who funded this research.

Paper context

Effective interventions are urgently needed to halt the increase in obesity in rural African populations, particularly given the scarcity of health resources to manage the consequent chronic non-communicable diseases. We demonstrate that while some predictors of higher body mass index in middle-aged and older adults in rural South Africa vary by sex, being married is a risk factor in both sexes and married couples may provide a target for public health interventions to reduce obesity.

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References

[1] Collinson MA, White MJ, Bocquier P, et al. Migration and the epidemiological transition insights from the Agincourt sub district of northeast South Africa. Glob Health Action. 2014;7:23514.
[2] Mayosi BM, Flisher AJ, Laloo UG, et al. The burden of non-communicable diseases in South Africa. Lancet. 2009;374:934–947.
[3] Streatham PK, Khan WA, Bhuinya A, et al. Mortality from external causes in Africa and Asia: evidence from INDEPTH health and demographic surveillance system sites. Glob Health Action. 2014;7:25366.
[4] Abubakari AR, Lauder W, Ayegemang C, et al. Prevalence and time trends in obesity among adult West African populations: a meta-analysis. Obes Rev. 2008;9:297–311.
[5] Joubert J, Norman R, Bradshaw D, et al. Estimating the burden of disease attributable to excess body weight in South Africa in 2000. S Afr Med J. 2007;97:683–690.
[6] NCD Risk Factor Collaboration (NCD-RisC). Worldwide trends in body-mass index, underweight, overweight, and obesity from 1975 to 2016: a pooled analysis of 2416 population-based measurement studies in 128.9 million children, adolescents, and adults. Lancet. 2017;390:2627–2642.
[7] Ayegemang C, Boatemaas S, Frempong GA, et al. Obesity in sub-Saharan Africa. In: Ahima R editor. Metabolic syndrome. Cham: Springer International Publishing; 2015. p. 41–53.
[8] Shisana O, Labadarios D, Rehle T, et al. The South African National Health and Nutrition Examination Survey (SANHANES-1). Cape Town: HSRC Press; 2014.
[9] Moodley G, Christofides N, Norris S, et al. Obesogenic environments: access to and advertising of sugar-sweetened beverages in Soweto, South Africa. Prev Chronic Dis. 2015;12:E186.
[10] Lundeen EA, Norris SA, Adair LS, et al. Sex differences in obesity incidence: 20-year prospective cohort in South Africa. Pediatr Obes. 2016;11:75–80.
[11] Otang-Mbeng W, Otunola GA, Afolayan AJ. Lifestyle factors and co-morbidities associated with obesity and overweight in Nkonkobe Municipality of the Eastern Cape, South Africa. J Health Popul Nutr. 2017;36:22.
[12] Okop KJ, Levitt N, Puaone 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.

[13] Gradidge PJ, Norris SA, Munthali R, et al. 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.

[14] Gómez-Olivé FX, Ali SÀ, Made F, et al. Regional and sex differences in the prevalence and awareness of hypertension: an H3Africa AWI-Gen study across 6 sites in sub-Saharan Africa. Glob Heart. 2017;12:81–90.

[15] Kahn K, Collinson MA, Gómez-Olivé FX, et al. Profile: agincourt health and socio-demographic surveillance system. Int J Epidemiol. 2012;41:988–1001.

[16] Ramsay M, Crowther N, Tambo E, et al. H3Africa AWI-Gen Collaborative Centre: a resource to study the interplay between genomic and environmental risk factors for cardiometabolic diseases in four sub-Saharan African countries. Glob Health Epidemiol Genom. 2016;1:e20.

[17] Clark SJ, Gómez-Olivé FX, Houle B, et al. Cardiometabolic disease risk and HIV status in rural South Africa: establishing a baseline. BMC Public Health. 2015;15:135.

[18] Gómez-Olivé FX, Thorogood M, Clark B, et al. Self-reported health and health care use in an ageing population in the Agincourt sub-district of rural South Africa. Glob Health Action. 2013;6:e19305.

[19] Gómez-Olivé FX, Montana L, Wagner RG, et al. Cohort profile: health and ageing in Africa: a longitudinal study of an INDEPTH community in South Africa (HAALSI). Int J Epidemiol. 2018;47:689–690.

[20] Vyas S, Kumararayanak E. Constructing socio-economic status indices: how to use principal components analysis. Health Policy Plan. 2006;21:459–468.

[21] Kabudula CW, Houle B, Collinson MA, et al. Socioeconomic differences in mortality in the antiretroviral therapy era in Agincourt, rural South Africa, 2001–13: a population surveillance analysis. Lancet Glob Health. 2017;5:e924–e935.

[22] Ewing JA. Detecting alcoholism: the CAGE questionnaire. JAMA. 1984;252:1905–1907.

[23] Harris PA, Taylor R, Thielke R, et al. Research electronic data capture (REDCap) - a metadata driven methodology and workflow process for providing translational research informatict support. J Biomed Inform. 2009;42:377–381.

[24] Agymang C, Meeks K, Beune E, et al. Obesity and type 2 diabetes in sub-Saharan Africans - is the burden in today's Africa similar to African migrants in Europe? The RODAM study. BMC Med. 2016;14:166.

[25] Kirunda BE, Fadnes LT, Wamani H, et al. Population-based survey of overweight and obesity and the associated factors in peri-urban and rural Eastern Uganda. BMC Public Health. 2015;15:1168.

[26] Pasquet P, Temgoua LS, Melaman-Sego F, et al. Prevalence of overweight and obesity for urban adults in Cameroon. Ann Hum Biol. 2003;30:551–562.

[27] Case A, Menendez A. Sex differences in obesity rates in poor countries: evidence from South Africa. Econ Hum Biol. 2009;7:271–282.

[28] Klos LA, Sobal J. Marital status and body weight, weight perception, and weight management among U.S. adults. Eat Behav. 2013;14:500–507.

[29] Mata J, Frank R, Hertwig R. Higher body mass index, less exercise, but healthier eating in married adults: nine representative surveys across Europe. Soc Sci Med. 2015;138:119–127.

[30] Shayo GA, Mugusi FM. Prevalence of obesity and associated risk factors among adults in Kinondoni municipal district, Dar es Salaam Tanzania. BMC Public Health. 2011;11:365.

[31] Umberson D, Liu H, Powers D. Marital status, marital transitions, and body weight. J Health Soc Behav. 2009;50:327–343.

[32] Shahar DR, Schultz R, Shahar A, et al. The effect of widowhood on weight change, dietary intake, and eating behavior in the elderly population. J Ageing Health. 2001;13:186–199.

[33] Dare S, Mackay DF, Pell JP. Relationship between smoking and obesity: a cross-sectional study of 499,504 middle-aged adults in the UK general population. PLoS One. 2015;10:e0123579.

[34] Akarolo-Anthony SN, Willett WC, Spiegelman D, et al. Obesity epidemic has emerged among Nigerians. BMC Public Health. 2014;14:455.

[35] Alaba O, Chola L. Socioeconomic inequalities in adult obesity prevalence in South Africa: a decomposition analysis. Int J Environ Res Public Health. 2014;11:3387–3406.

[36] Drewnowski A, Vernez Moudon A, Jiao J, et al. Food environment and socioeconomic status influence obesity rates in Seattle and in Paris. Int J Obes. 2014;38:306–314.

[37] Conklin AI, Forouhi NG, Subarke M, et al. Socioeconomic status, financial hardship and measured obesity in older adults: a cross-sectional study of the EPIC-Norfolk cohort. BMC Public Health. 2013;13:1039.

[38] Monteiro CA, Moura EC, Conde WL, et al. Socioeconomic status and obesity in adult populations of developing countries: a review. Bull World Health Organ. 2004;82:940–946.

[39] Draper CE, Davidowitz KJ, Goedecke JH. Perceptions relating to body size, weight loss and weight-loss interventions in black South African women: a qualitative study. Public Health Nutr. 2016;19:548–556.

[40] Manne-Goehler J, Montana L, Gómez-Olivé FX, et al. The ART advantage: health care utilisation for diabetes and hypertension in rural South Africa. J Acquir Immune Defic Syndr. 2017;75:561–567.

[41] Huis’t Veld DB, Balestre E, Buyze J, et al. Determinants of weight evolution among HIV-positive patients initiating antiretroviral treatment in low-resource settings. J Acquir Immune Defic Syndr. 2015;70:146–154.

[42] Ross LJ, Wilson M, Banks M, et al. Prevalence of malnutrition and nutritional risk factors in patients undergoing alcohol and drug treatment. Nutrition. 2012;28:738–743.

[43] Pillay-van Wyk V, Msimburi W, Laubscher R, et al. Mortality trends and differentials in South Africa from 1997 to 2012: second national burden of disease study. Lancet Glob Health. 2016;4:e642–653.