FACTORS ASSOCIATED WITH OBESITY AND METABOLIC SYNDROME IN AN AGEING COHORT OF BLACK WOMEN LIVING IN SOWETO, JOHANNESBURG (STUDY OF WOMEN IN AND ENTERING ENDOCRINE TRANSITION [SWEET])

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A thesis submitted to the
Department of Paediatrics
Faculty of Health Sciences
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Degree of Doctor of Philosophy

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DECLARATION

I, Philippe Jean–Luc Gradidge, declare that this thesis is my own work. It is being submitted for the Degree of Doctor of Philosophy at the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at this or any other University. The required convention for referencing the work and material of others has been followed.

……

P J–L Gradidge

Date: 26th day of July 2016

For

Katherine

Luc

Annabella

STUDENT'S CONTRIBUTION TO THE WORK PRESENTED IN THE THESIS

Together with my supervisors, I was involved in the conceptualisation of the new data collection for the thesis.

I was involved in the development of the survey protocol, which included formulating the standard operating procedure, data collection, information sheet, and informed consent.

I collected data on the physical activity, psycho–social and sitting time survey instruments.

In addition, I contributed to quality control and data management for the survey.

My specific responsibilities for the three publications are outlined below and all the co–authors of these manuscripts have approved the inclusion of these in the thesis (see Appendix 17)

PUBLICATIONS ARISING FROM THE RESEARCH

1. Gradidge PJ, Crowther NJ, Chirwa ED, Norris SA, Micklesfield LK (2014) **Patterns, levels and correlates of self–reported physical activity in urban Soweto women**. *BMC Public Health* 2014, **14**:934. (Appendix 9)

Contributions to the paper

Philippe J. Gradidge, Esnat D. Chirwa, and Nigel J. Crowther performed the statistical analysis and Philippe J. Gradidge wrote the paper. Shane A. Norris and Lisa K. Micklesfield

conceived and implemented the study. All authors read and commented on the paper. All authors approved the final version of the manuscript.

2. Gradidge PJ, Norris SA, Micklesfield LK, Crowther NJ (2015) **The role of lifestyle and psycho–social factors in predicting changes in body composition in black South African women** *PLoS One*, **10**(7):e0132914. (Appendix 10)

Contributions to the paper

Philippe J. Gradidge and Nigel J. Crowther performed the statistical analysis and Philippe J. Gradidge wrote the paper. All authors conceived the experiments and Philippe J. Gradidge implemented the study. All authors read and commented on the paper. All authors approved the final version of the manuscript.

3. Gradidge PJ, Norris SA, Jaff NG, Crowther NJ

Metabolic and body composition risk factors associated with metabolic syndrome in a cohort of women with a high prevalence of cardiometabolic diseases

Plos One (under review)

Contributions to the paper

Philippe J. Gradidge and Nigel J. Crowther performed the statistical analyses, interpreted the data and wrote the paper. Philippe J. Gradidge, Nigel J. Crowther and Shane A. Norris conceived the experiments, and Philippe J. Gradidge and Nicole G. Jaff collected the data. All authors read and commented on the paper. All authors approved the final version of the manuscript.

CONFERENCE PROCEEDINGS

1. Gradidge PJ, Crowther NJ, Norris SA, Micklesfield LK

Title: Physical activity and sedentary behaviour in urban South African women: impact on metabolic disease risk and body composition.

Conference: Faculty of Health Sciences Bi–Annual Research Conference

Date: 19 September 2012

Place: University of the Witwatersrand, South Africa.

2. Gradidge PJ, Crowther NJ, Norris SA, Micklesfield LK

Title: Patterns, levels and correlates of physical activity in urban black Soweto women.

Conference: The 11th International Conference on Urban Health

Date: 4–7 March 2014

Place: University of Manchester, United Kingdom.

GRANTS

Title of grant: Carnegie Large Grant

Principal investigator: Mr. Philippe Gradidge

Co–investigators: Prof. Shane Norris, Prof. Nigel Crowther, and Dr. Lisa Micklesfield

Total amount allocated: R200 000.00

The money was used for:

- Contributing towards analysis of lipid profile, fasting glucose and fasting insulin for N=450: Total cost – R121801.50
- Attending the 11th International Conference on Urban Health: Total cost – R42592.30
- Research assistance: Total cost – R35602.20

ABSTRACT

Background: Black South African women living in urban settings have the highest prevalence of obesity in the sub–Saharan African region, and consequently a high prevalence of cardiometabolic diseases. The risk factors for obesity and the metabolic syndrome are not well studied in this population group, and the inter–relationship between diseases risk factors for metabolic syndrome is poorly understood, in addition to whether one factor predominates.

Aim: The aim is three–fold: (i) To assess the physical activity patterns of middle–aged, urban black South African women, and if these patterns are associated with metabolic outcomes; (ii) To examine the association between lifestyle and psycho–social factors and changes in body composition over 10 years in this population; and (iii) To identify risk factors for the various components of metabolic syndrome.

Methods: Drawing on the longitudinal Birth to Twenty Plus cohort (a longitudinal study of the health and development of children and their families) data collected in 2003 and 2013 was used to address the respective aims of the thesis. In particular, data on (i) anthropometry; (ii) body composition; (iii) blood pressure; (iv) cardiometabolic markers; (v) environmental factors (physical activity, smoking and smokeless tobacco consumption, and alcohol consumption); (vi) psycho–social factors; (vii) socio–economic status; and (viii) education status was used. Analytical methods comprised of descriptive, correlations, comparisons, multivariable regression, and logistic regression. Paper 1 described the patterns, levels and correlates of physical activity in 977 African women. Paper 2 was a longitudinal study of the role of environmental and psycho–social factors in predicting changes in body composition over 10 years (N=430). Body composition from ultrasound and DXA analyses, blood pressure, cardiometabolic and demographic factors were measured in 702 black African women from Soweto, Johannesburg for paper 3, which was a descriptive, cross–sectional study using data from the 2011/13 wave of data collection.

Results: The prevalence of obesity (48.0% (baseline) to 67.8% (follow–up)) and metabolic syndrome (40.0% (baseline) to 49.6% (follow–up) increased significantly over ten years. The majority of the population were classified as "active" according to global physical activity questionnaire criteria, and the domain that contributed most to overall weekly physical activity was walking for travel. Sitting time (mins/wk) was not different between the activity groups, but was positively associated with triglyceride levels and diastolic blood pressure. Total physical activity was inversely associated with fasting insulin, and physical activity in the work domain was associated with fat–free, soft–tissue mass. Two distinct groups of overweight/obese females were identified using body–size dissatisfaction and body–size discrepancy scores: one that was content with their body–size and one that wished to be leaner. Vigorous physical activity at baseline was inversely associated with absolute changes in all measures of adiposity. In subjects who underestimated their body–size at baseline (74.0 % of the study population) changes in total and peripheral levels of body fat were less than in subjects who correctly identified their body–size. In the group that underestimated body–size, more women wanted to be leaner than in the group who knew their body–size (60.1 % vs 47.5 %, $p < 0.05$). Logistic regression analysis demonstrated that adiponectin (odds ratio [95% CIs]: 0.84 [0.77, 0.92], $p<0.0005$) and abdominal subcutaneous fat (0.56 [0.39, 0.79], $p=0.001$) reduced metabolic syndrome risk whilst insulin resistance (1.31 [1.16, 1.48], $p<0.0005$) and trunk fat–free, soft–tissue mass (1.34 [1.10, 1.61], $p=0.002$) increased risk. Within this group of risk factors, the relationship of adiponectin with metabolic syndrome risk, when analysed across adiponectin hexiles, was the least affected by adjustment for the other risk factors.

Conclusions: The findings of this thesis show that the majority of urban black South African women have a high prevalence of obesity and cardiometabolic disease risk factors despite being classified as 'physically active'. However, the intensity of the respective domains of physical activity is unknown. As walking as a means of travel/transport is a major contributor to physical activity, future research should attempt to determine whether the intensity of this activity plays a role in the prevention of cardiometabolic diseases. It was also demonstrated that an underestimation of body–size is common and is associated with a lower gain in total body adiposity and a desire to lose weight in most of the participants. Finally, this thesis observed that adiponectin has a significant protective role against metabolic syndrome that is independent of other risk factors. The protective and augmentive

effects of abdominal subcutaneous fat and lean trunk mass, respectively, on metabolic syndrome risk demonstrate the existence of novel interactions between body composition and cardiometabolic disease.

ACKNOWLEDGEMENTS

I would like to acknowledge the following individuals whose inspiration, support and optimism have assisted in making this doctoral thesis a reality:

- Professors Shane Norris and Nigel Crowther, my supervisors, for contributing to the design of the study, assistance with statistical analyses for the publications, and guidance during the writing process, and overall mentorship.
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- Dr. Esnat Chirwa for assisting with statistical analysis in paper 1.
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- The women from the Birth–to–Twenty longitudinal cohort study who volunteered to participate in this study.
- The research team from Soweto, Johannesburg who assisted with the data collection.

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LIST OF ABBREVIATIONS, ACRONYMS, AND GLOSSARY

Bt20:	Birth–to–Twenty study
BMI:	Body mass index
BP:	Blood pressure
CETP:	Cholesterol ester transfer protein
cm:	Centimetre (s)
CV:	Coefficient of variation
DBP:	Diastolic blood pressure
DXA:	Dual energy X–ray Absorptiometry
FFA:	Free fatty acids
FFSTM:	Fat–free, soft–tissue mass
FH	Familial hypercholesterolaemia
FI:	Fasting insulin
FID:	Feel–minus–Ideal score
FM:	Fat mass
FPRNa:	Fractional sodium reabsorption
GPAQ:	Global physical activity questionnaire
HbA_{1c}:	Glycated haemoglobin
HC:	Hip circumference
HDL:	High–density lipoprotein cholesterol
HOMA:	Homeostasis model assessment
IDF:	International Diabetes Federation
IFG:	Impaired fasting glucose
kg:	Kilogram (s)
$kg.m^{-2}$:	Kilogram (s) per metre squared
LDL:	Low–density lipoprotein cholesterol
LMIC:	Low– and middle–income countries
m:	Metre (s)
m^2:	Metre (s) squared
MET (s):	Metabolic equivalent (s)
$min.week^{-1}$:	Minute (s) per week
$mmol.L^{-1}$:	Millimole (s) per litre
MVPA:	Moderate–vigorous physical activity
NCD:	Non–communicable disease (s)

NCEP:	National Cholesterol Education Program Expert Panel, Adult Treatment Panel III
PA:	Physical activity
PAD:	Perceived and actual weight status
SANHANES:	South African National Health and Nutrition Examination Survey
SBP:	Systolic blood pressure
SCAT:	Subcutaneous adipose tissue
SES:	Socio–economic status
TC:	Total cholesterol
TG:	Triglyceride
THUSA:	Transition and Health during Urbanisation of South Africans study
TSNA (s):	Tobacco–specific N–nitrosamine (s)
US:	Ultrasound
USA:	United States of America
VAT:	Visceral adipose tissue
WC:	Waist circumference
WHO:	World Health Organisation

PREFACE

The 2010 Wits Faculty of Health Sciences' Prestigious Research Lecture entitled, "Mandela's Children: Securing the health and well–being of future generations," was the main motivator for this doctoral study (1). The speakers highlighted the main health challenges of children and infants in South Africa, and how these were possibly related to the adult manifestation of disease, particularly in black South African women living in urban settings. The researcher was intrigued to learn of the increasing obesity epidemic in the country and its influence on metabolic syndrome in these women.

The obesity epidemic has become more noticeable in children and adults since 2000, with low–and–middle–income countries (LMIC) predicted to continue increasing, yet seems to be decelerating in richer countries (2). Obesity is a complex multifaceted disease, which is thought to be strongly related to lifestyle behaviours, and is linked to hypercholesterolaemia, hypertension, and other chronic diseases (3). A worrying observation is the increasing prevalence of metabolic syndrome in African women (4), an entity that has been shown to increase the risk of cardiac events and diabetes. Traditional African culture has demonstrated a social preference for larger body–size and general tolerance of obesity in African women (5). These psycho–social factors and the fact that an urban environment is more obesogenic than a rural setting, poses a greater risk of obesity and related diseases in urbanised black South African women.

An opportunity to investigate this trend further developed when I was granted permission, as part of my PhD project, to recruit caregivers from the Birth–to–Twenty (Bt20) study, based in Soweto, Johannesburg (6). The researcher was able to collect advanced body composition data using dual energy x–ray absorptiometry and ultrasonography, and to document body image perception, and the level of physical activity of the women as a result of the equipment and tools available at Bt20. Therefore, the results of this thesis add to the limited evidence regarding body fat distribution, biochemical, environmental and psycho–social factors associated with obesity and related cardiometabolic disorders in black South African women.

STRUCTURE OF THE DOCUMENT

The thesis is with publications and there are three parts to the thesis (Figure 1.1).

- Part 1 of the thesis comprises the literature review and the consolidated methodology, Chapters 1 and 2, respectively.
- Part 2 of the thesis encompasses the results Chapters 3, 4, and 5 which contain the findings of the studies.
- Part 3 is the final component of the thesis and includes the conclusions and suggestions for future research (Chapter 6).

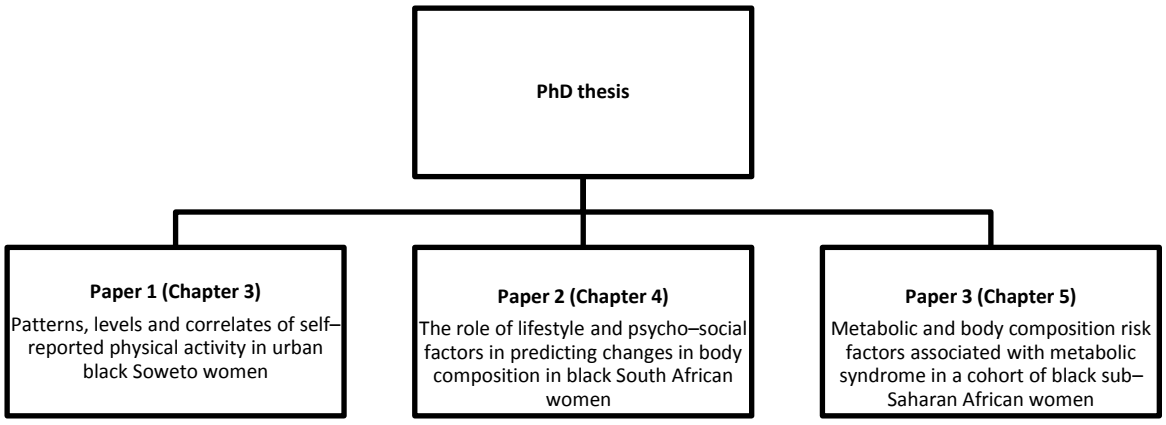


Figure 1.1: Graphical representation of the publications in this PhD thesis

PART 1

CHAPTER 1 – LITERATURE REVIEW

1.1 Introduction

The constellation of components that form the metabolic syndrome are prevalent in black African transitioning societies (2, 4, 7-9). Primary health care in South Africa is currently being reformed into one that is more inclusive and multi–disciplinary (10). The focus is shifting away from community clinics that only specialise on individual non–communicable diseases (NCD) such as diabetes or hypertension as discrete components towards a holistic approach to disease management whereby one clinic is able to deal with multiple disorders (11). Given the fact that the South African health care system is being re–engineered it is important to look at the components of metabolic syndrome not as discrete and individualistic but more as a constellation of factors. Even though there are some that criticise the use of the term 'metabolic syndrome', most critics have settled on the fact that there are subjects who have a higher risk of cardiometabolic diseases compared with others (12-14). Therefore a critical part of impacting or intervening on the high prevalence of obesity and metabolic syndrome in black South African women is to understand the contributing factors driving these diseases.

1.2 Conceptual Framework

The conceptual framework used for this thesis is displayed in Figure 1.2. It has been adapted and modified from Brunzell et al. (15) whose model suggests that the risk factors for cardiovascular disease can appear as individual elements, that lead to the emergence of a collection of various cardiometabolic diseases, essentially represented by the metabolic syndrome. Since the clustering of these elements increases the overall risk of morbidity and cardiovascular disease (16), it is important to determine the underlying risk factors involved.

Data from other developing African countries undergoing rapid urbanisation demonstrate that the prevalence of the separate metabolic syndrome components are higher in urban dwelling women compared with those living in the rural setting (17-19). Obesity has a positive association with metabolic syndrome (20), and can result in endocrine abnormalities and early mortality as illustrated in Figure 1.2. There is a lack of data on the physical activity

patterns of African populations (21), and the influence of psycho–social factors on obesity is not confirmed in adult African women (22). Therefore, the framework also depicts the possible influence of socio–economic, lifestyle and psycho–social factors on obesity and metabolic syndrome. Identifying the risk factors influencing obesity and metabolic syndrome is fundamental to understanding the high prevalence of the individual cardiometabolic diseases in black South African women, particularly in those women living in urban areas who seem to be more susceptible to this phenomenon.

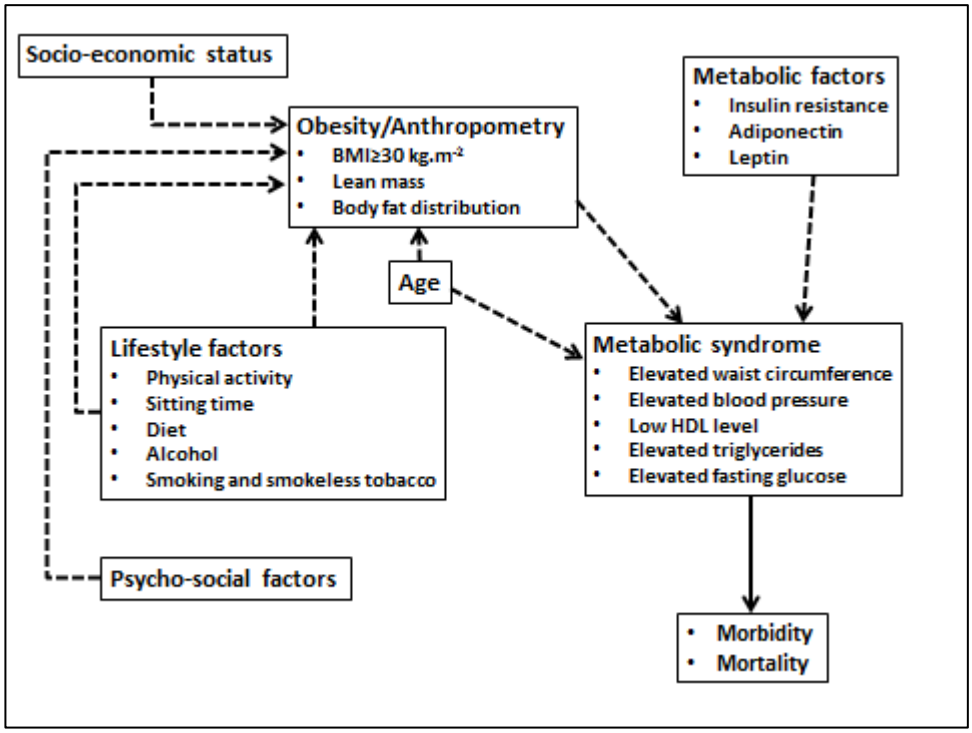


Figure 1.2: Potential factors associated with obesity and metabolic syndrome; adapted from: Brunzell et al. (2008) (15). The proposed linkages between the elements are represented by dashed lines in this conceptual, hypothetical framework.

The subsequent sections provide an overview of the possible risk factors for obesity and metabolic syndrome, followed by a review of the studies examining the contribution of body composition, metabolic factors, psycho–social factors, socio–economic status, and environmental factors on the development of metabolic syndrome.

1.3 Obesity

1.3.1 Background

In Africa, women notably have higher body mass index (BMI) values than men, and black South African women have the greatest obesity prevalence in the sub–Saharan African region (2). Black women in South Africa are more affected by NCDs compared with men (23), a development which is characteristic of other countries on the African continent and LMICs (24, 25). Furthermore, obesity is higher in urban black South African women compared with those women living in rural South Africa (26), and the increasing movement of populations from rural to urban settings is an important contributing factor to the obesity epidemic in sub–Saharan Africa (27-29).

Urbanisation in Africa is known to encompass the adoption of behaviours such as unhealthy eating and physical inactivity (30). Therefore, urban–dwelling black South African women are also estimated to expend less energy than rural women (21, 31), and are considerably more sedentary (32). These lifestyle behaviours are thought to influence obesity and its related disorders, particularly resulting in higher fat accumulation and insulin resistance in black Africans compared with white subjects (33). Other behavioural factors that increase obesity risk are tobacco use and the overconsumption of alcohol and dietary fats (34). As people transition, walking as a means of transport decreases as socio–economic status (SES) improves (35), which is concerning for the future risk of metabolic syndrome in African populations. Black South African women are also generally poorer; less educated and have lower SES levels than other population groups in the country (36). These factors have been associated with the obesity epidemic in African women (22). Moreover, traditional beliefs around body image have been demonstrated to impact on obesity, driven mostly by a general acceptance of larger body–size in African populations (22). In the following sections I will discuss factors specific for obesity and in a later section I will discuss factors common to obesity and metabolic syndrome.

1.3.2 Definition

Obesity is a disease characterized by both fat deposition of new fat cells and an increase in the size of existing cells that endangers health (37). It was generally thought that excess body fat deposition resulted from a discrepancy between energy output (physical activity) and energy intake (caloric intake). The result is a positive energy balance and if this pattern continues, overweight and obesity will develop over time. In essence, traditional thinking attributed obesity to an excess intake of food, and not enough physical activity. The aetiology regarding obesity is however more complex than this simplistic theoretical model. For example, energy output can be in the form of erratic behaviour such as restlessness while sitting (38), a percentage of the food consumed is eliminated during the digestive process rather than absorbed (39), and most of the available tools for the measurement of energy output do not account for these confounding factors. The present lifestyles of South Africans have been made easier by the global technological advancement, resulting in vocations that require minimal energy expenditure (40, 41). Although caloric intake has been shown to be associated with obesity (42), factors such as hereditary and smoking may also be associated with lower risk of weight gain, implying that obesity is not simply a disease of over consumption. Bouchard et al. for example have shown that the variance in weight gain could be attributed to heredity factors (43, 44), while a Danish adoption study observed that the BMI categories of adoptees and their biological parents were correlated (45). These studies suggest that genetics has a major input into determining body fat mass.

Approximately three million deaths globally are caused by cardiometabolic diseases such as diabetes annually, for which excessive body weight is one of the main risk factors (46, 47). A crude measure used to determine excess body weight is body mass index (BMI), which uses a weight for height index to reflect adult total body fat (48). It is calculated by dividing the persons total body weight (kg) by the square of the standing height (in metres). Categories of BMI include normal (BMI$\geq$18.5 and <25 kg/m^2), overweight (BMI: $\geq$25, but <30 kg/m^2), and obesity (BMI: $\geq$30 kg/m^2). Health problems related to excess body weight increase from a BMI >25 (overweight and obesity categories of BMI) (48). The main disadvantage of BMI is that it does not distinguish between muscle mass, adipose tissue or bone; however, increased risk of coronary artery disease, hypertension, dyslipidaemia, and mortality have a direct relationship with BMI (Table 1.1) (49)

Table 1.1: Body mass index (BMI) and waist circumference used to classify risk of disease for hypertension, cardiovascular disease, and type 2 diabetes

Risk of disease [a] relative to normal body weight and waist circumference			
BMI category	**BMI (kg/m^2)**	**Men, ≤102 cm Women, ≤88 cm**	**Men, >102 cm Women, >88 cm**
Underweight	<18.5	–	–
Normal	18.5-24.9	–	–
Overweight	25.0-29.9	Increased	High
Obesity, class			
I	30.0-34.9	High	Very high
II	35.0-39.9	Very high	Very high
III	≥40	Extremely high	Extremely high

[a] Dashes (-) specify that that there was no further risk allocated at these levels of BMI.

Information from Expert panel: Clinical guidelines on the identification, evaluation, and treatment of overweight and obesity in adults: executive summary. The American Journal of Clinical Nutrition 1998, 68:899–917 (50)

Waist circumference is a proxy measure of central obesity, and is a good indicator of disease risk (50). The cut off levels for waist circumference in Table 1.1 are currently used in the diagnosis of the metabolic syndrome by the National Cholesterol Education Program (NCEP) (51), while the European Group for the Study of Insulin Resistance use slightly lower levels of ≥80 and ≥94 cm, in women and men respectively (52). The International Diabetes Federation (IDF) uses the latter cut points, and when compared with NCEP, most of the same individuals are classified with metabolic syndrome, thus demonstrating their similarity (53). In sub–Saharan African countries such as South Africa, the IDF cut–off for waist circumference is recognised (16). Another proxy indicator of visceral obesity is waist–

to–hip ratio, which although studies have shown an association of this measure with type 2 diabetes, the wider scientific community debates the clinical usefulness of this ratio as a predictor of metabolic diseases (54). Intrinsic factors such as population group, gender and age may determine the worth of using waist–to–hip ratio as these confounding factors have been shown to influence body composition outcomes (54). Nevertheless, the use of ratios can be problematic due to the difficulty of biological interpretation, low sensitivity to weight change, and the high likelihood of statistical error when conducting analyses (55). Thus, the evidence suggests that BMI and waist circumference seem to be better indicators of obesity compared with waist–to–hip ratio.

1.3.3 Epidemiology

Excessive body weight was previously thought to be a problem of mostly developed countries as a result of overconsumption and high economic stature (56); however, the burden of obesity has become a global phenomenon affecting countries across the economic spectrum.

Overweight and obesity prevalence has risen since 1980 as has the prevalence of comorbid diseases which have been accompanied by an increased risk of premature mortality and morbidity (57). The increase in obesity is described as pandemic (58), affecting millions of people worldwide, and is expected to advance more rapidly in the next 16 years (59). In 1990, nearly two million deaths could be linked to excess body weight (60). Ten years later, the number of deaths attributable to overweight and obesity rose by 1.44 million. The global burden of diseases has shifted from a focus on children–related communicable diseases to NCDs in the adult population, which includes the key components of metabolic syndrome (60). The increasing prevalence of overweight and obesity is also associated with a reduction in longevity and life expectancy in developed countries (61).

The international patterns of obesity prevalence vary noticeably across countries (Table 1.2). In developing countries, the proportion of those subjects with obesity in the population is high and is estimated to further increase (2). In some of the LMICs, the countries have

transitioned from a chronic energy deficient state to one of over nutrition, but in other developing countries these extremes of nutrition can coexist within the same region or country (56). In comparison, developed countries have had a marked increase in the incidence of obesity between 1980 and 2006, however from 2006 to 2013 the rate of incidence has decreased (2). The prevalence of obesity likewise differs across regions (62). The BMI increase between 1980 and 2008 was highest in the tropical regions of Oceania, such as Tonga and Samoa, while some central and eastern European countries displayed near zero increases or slight decreases for women (62). Evidence from Ng et al. (2) highlights that men in developing countries have lower prevalence rates of overweight and obesity compared with women; while in developed countries the prevalence of obesity is similar across the genders. In the African region, women have higher BMI values compared with men (2).

Table 1.2 2013 Age–standardised country estimates of obesity for men and women, including comprehensive South African data (SANHANES)

Region/country	**Men**	**Women**
Angola	12.0 (10.7, 13.4)	18.7 (16.7, 20.9)
Argentina	21.2 (19.1, 23.3)	20.4 (18.3, 22.6)
China	3.8 (3.5, 4.3)	5.0 (4.5, 5.5)
Fiji	14.8 (13.3, 16.5)	35.4 (32.6, 38.8)
Japan	4.5 (4.0, 5.0)	3.3 (3.0, 3.7)
Kenya	6.3 (5.6, 7.2)	15.2 (13.7, 16.8)
Lesotho	6.9 (6.2, 7.6)	31.3 (29.7, 32.8)
Mozambique	3.5 (3.0, 3.9)	9.2 (8.3, 10.3)
Russia	15.3 (13.8, 17.0)	28.5 (26.1, 30.9)
Singapore	12.0 (10.7, 13.4)	10.8 (9.6, 12.0)
Tonga	52.4 (49.7, 55.2)	67.2 (64.5, 69.9)
Turkey	20.1 (18.7, 21.3)	34.1 (32.4, 35.8)
United Kingdom	24.5 (23.4, 25.7)	25.4 (24.2, 26.6)
United States of America	31.7 (30.0, 33.4)	33.9 (31.8, 35.7)
Vietnam	1.5 (1.3, 1.7)	1.7 (1.4, 1.9)
South Africa	10.6 (8.6, 12.6)	39.2 (37.0, 41.5)
Urban South Africa	13.2 (9.8, 16.7)	42.2 (38.4, 45.9)
Rural South Africa	6.1 (2.9, 9.3)	31.8 (27.3, 36.3)
Black South African	9.4 (7.4, 11.4)	39.9 (37.4, 42.4)
Caucasian South African	*	*
Coloured/mixed ethnicity South African	15.1 (9.3, 21.0)	34.9 (30.6, 39.2)
Asian/Indian South African	7.6 (1.2, 14.0)	32.4 (17.5, 47.3)
*Caucasian South African sample too low for reliable reporting (N=65 for men, and N=79 for women)		

In the sub–Saharan African region, it is South African women who have the highest prevalence of obesity (2). Black South African women are more affected by NCDs than men (23), a situation which is characteristic of other African and developing countries (24, 25). This suggests that black South African females have a higher likelihood of metabolic syndrome compared with white females living in the country. Table 1.3 displays that obesity

is more prevalent in the urban setting compared with the rural. The ethnic differences in obesity prevalence are also clear, and South Africa has the best data to show these differences because of the country's ethnic assortment.

1.3.4 Psycho–social factors

The misperception of body–size can influence the risk of overweight and obesity (63). Another important factor that could determine excess BMI is a dissatisfaction with current body image, indicating that some may have a desire to be thinner, others content with body–size, and still others wanting to have a larger body–size (64). In certain Western societies, BMI is positively associated with body–size dissatisfaction, and males have lower body–size dissatisfaction compared with females (65, 66).

Within African populations a number of cultural beliefs exist pertaining to body–size preference (22). These include a social desire to have a large body–size and a general tendency for men to choose women in the higher BMI categories (67). Previous studies in South Africa using body silhouettes to determine body–size perception have shown that black African females tend not to be satisfied with the way they look (Figure 1.3) (26, 68), suggesting a high level of body–weight discrepancy between how they currently look and what they envisage their ideal body–size and shape to be. The use of body silhouettes to distinguish the body-size dissatisfaction of black South African women has been validated (69, 70).

Traditionally a larger body–size is favoured more by black South African women (5, 67, 71), whereas being lean is considered to be weak, and linked with scarcity and chronic infectious diseases (72). Black South African women with higher BMI also feel they are able to perform physical tasks requiring moderate muscle strength and household chores more easily compared with thinner women (73).

This cultural preference for obesity has led to behaviours in some populations that encourage weight gain in children and adolescents. For example, some African communities practise the tradition of force feeding young women to make them gain weight, making them more attractive brides for potential suitors (74, 75). Rearing plump children is also viewed as an indication of good parenting (67). The acceptance of a culturally appropriate larger body–size may also play a role on the eating habits of black women (76).

A recent study has shown that black South African adolescent females favoured body image silhouettes representing higher BMIs in comparison with white adolescent females (77). This study also demonstrated that when queried about the body–size they perceived their families wanted them to be, black female adolescents mostly selected those body silhouettes symbolising larger BMIs compared with white female adolescents. Another study in South Africa indicated that acculturation of young black African females may be taking place, and that the western principles regarding body–size preference may be clashing with the traditional African ideals (78). In addition, fewer white adolescent girls are dissatisfied with their bodies, and have a lower likelihood of controlling what they eat compared with black age–matched females (77). Similarly, black adolescent girls are more likely to develop disorders associated with dietary intake (such as anorexia or bulimia nervosa) or become preoccupied with the consumption of food as they transition into adulthood (77). This implies that black South African adolescent girls are more influenced by body–size perception compared with whites, which could partly explain the increasing prevalence of obesity in adult African women.

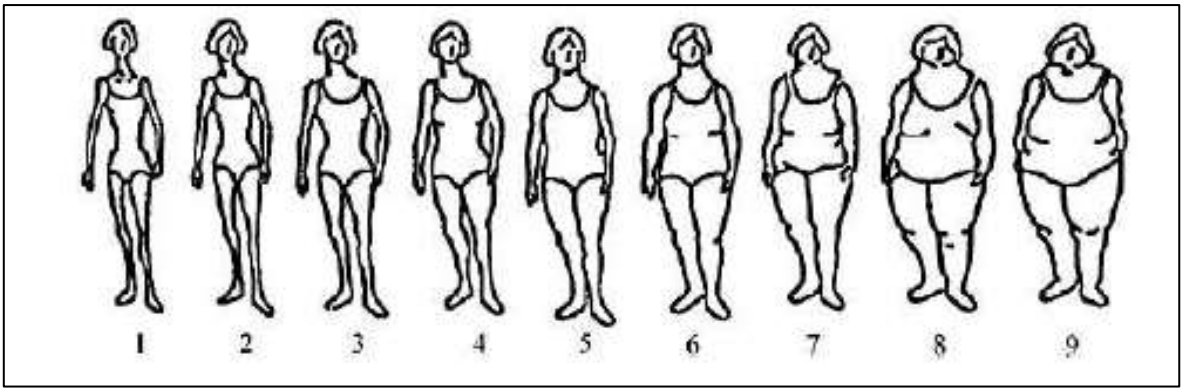
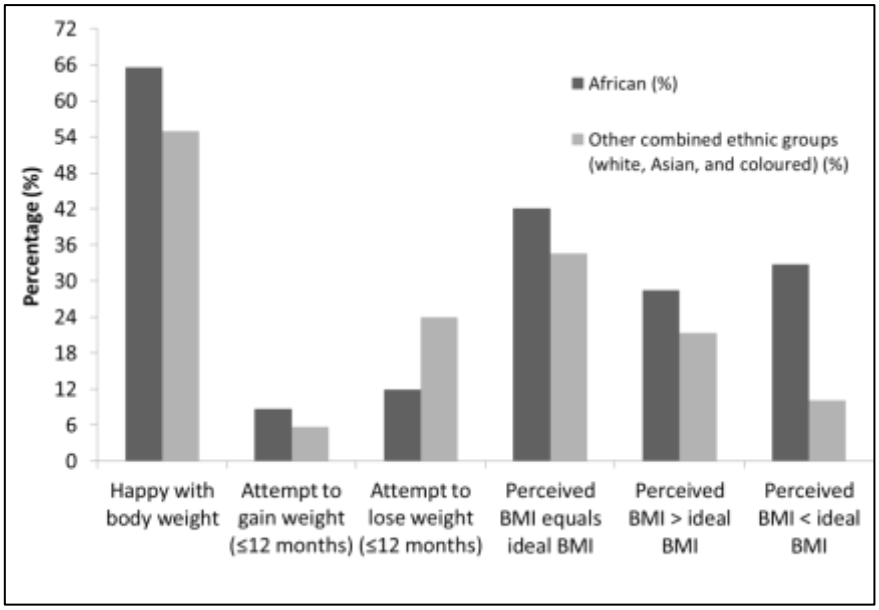


Figure 1.3: Body silhouettes used in the definition of fatness and thinness in black African women (source: Stunkard *et al.* (1983) (79))

However, data from the South African National Health and Nutrition Examination Survey (SANHANES) demonstrated that black South African women when compared to women from other ethnic groups are generally happier with current body weight and have a higher proportion of women whose perceived BMI is equal to actual BMI (Figure 1.4) (23). In contrast, other ethnic groups in South Africa have a higher percentage of women who attempted to lose weight in the past 12 months. This suggests that despite a high prevalence of excess BMI, the majority of black African women are content with their body–size, and are not concerned with managing weight gain.

Recent data showed that body–size dissatisfaction is experienced across various SES strata and, although the prevalence is highest in the obese category, those who displayed healthy dietary intake patterns also have a high prevalence of body–size dissatisfaction (66).



Source of data: SANHANES 2013 (23)
Figure 1.4: Body– size dissatisfaction, body–size discrepancy and weight management in black African women compared with other ethnic groups (coloured, white, and Indian ethnic groups) in South Africa

1.4 Metabolic syndrome

1.4.1 Background

People with obesity often exhibit other co–existent NCDs, indicating the possible interrelationship of risk factors (80). Metabolic syndrome is characterised by the clustering of numerous atherosclerotic, and cardiovascular disease risk factors, including raised blood pressure, hyperglycaemia, central obesity and dyslipidaemia (20). This constellation of cardiometabolic disease risk factors also increases the risk of type 2 diabetes, cardiovascular disease and all–cause mortality (16), each with an estimated relative risk of 2.99, 1.65 and 1.27 respectively (81). The underlying causes of the syndrome are uncertain, but fat gain seems to promote its onset, particularly when it occurs abdominally (80). Reaven suggested that insulin resistance was the main driver of metabolic syndrome (82), however more recently it has been proposed that large waist circumference, a proxy measure of intra–abdominal adiposity, and abnormal serum triglyceride concentration are central to the syndrome (83). I will discuss the factors specific for metabolic syndrome here, while those factors shared by obesity and metabolic syndrome will be discussed later.

1.4.2 Definition of "metabolic syndrome"

There are several definitions for "metabolic syndrome", but it is the National Cholesterol Education Program Expert Panel, Adult Treatment Panel III (NCEP) and The International Diabetes Federation (IDF) definitions that have most commonly been used. A positive diagnosis using the NCEP classification is made when 3 or more of the following cardiovascular disease risk factors are present: raised blood pressure, low high–density lipoprotein cholesterol (HDL) , impaired fasting blood glucose, hypertriglyceridemia, high waist circumference (Table 1.3) (84). In comparison, the IDF definition stresses ethnic–specific thresholds for central obesity (85). The two definitions have been compared, and found to be compatible (53). A new definition was proposed in 2009 by various organisations, which suggested harmonising the definitions of metabolic syndrome (16). Thus, rather than emphasising one particular component, 3 or more of the five components need to be present for a positive diagnosis, and region–specific cut–offs for central obesity were maintained. In South Africa, the Europid definition for waist circumference is still being used for the diagnosis, however a recent study suggested that this threshold should be increased in African women (4).

Table 1.3: Criteria used to identify metabolic syndrome in a population/cohort by means of two widely used guidelines and the new 'harmonised guidelines'*

Risk factors	National Cholesterol Education Program Expert Panel, Adult Treatment Panel III (NCEP)	International Diabetes Federation (IDF)	Harmonised guidelines
Abnormal waist circumference (cm)	≥102 (males) ≥88 (females)	≥94 (males) ≥80 (females)	≥94 (males) ≥80 (females)
High serum triglycerides (mmol.L^{-1})	≥1.7	NCEP or specific management	NCEP or specific management
Low high–density lipoprotein cholesterol (mmol.L^{-1})	<1.03 (males) <1.30 (females)	NCEP or specific management	<1.0 (males) <1.30 (females)
Elevated blood pressure (mm Hg)	≥130 (systolic) and/or ≥85 (diastolic)	NCEP or diagnosed hypertension	NCEP or diagnosed hypertension
Impaired fasting blood glucose (mmol.L^{-1})	≥6.10	≥5.6	≥5.6

*NCEP and Harmonised require 3 or more of 5 for diagnosis whilst IDF requires waist circumference plus 2 or more of rest.

1.4.3 Epidemiology of metabolic syndrome in African women

The increasing prevalence of obesity in LMICs correlates with the increasing presence of metabolic syndrome in various population groups. The incidence of the syndrome in black South African women is high using the IDF criteria (4), comparable to studies of other African women (7-9), and higher than most developing Asian countries and developed European countries (86) (Table 1.4). Table 1.4 also displays that most African countries have a higher proportion of women with the presence of the metabolic syndrome compared with men. When compared with rural black African populations (7), an estimated 13.6 % more women present with metabolic syndrome in the urban setting (4), which can be explained by the higher risk of obesity associated with the urban environment.

The previous thinking around what was considered the main driving force for the metabolic syndrome seemed to centre around insulin resistance (82, 87, 88), but more recent studies seem to agree on the fact that it is central obesity that is the key determinant of the syndrome (83). Data from studies performed in various African regions support this theory (4, 18, 89), showing that some components of the metabolic syndrome are more prominent than others in African populations. Thus, abdominal obesity, low HDL and elevated blood pressure are observed to be more noticeable compared with high serum triglycerides and elevated fasting glucose levels. Black South African (and African American) women have significantly less visceral adipose tissue compared with their white counterparts, and the association with peripheral insulin sensitivity is lower in black compared with white South African women (90-92). Moreover, the theory that visceral adiposity is the main driving factor of the metabolic syndrome in black sub–Saharan Africans has been shown (87).

Table 1.4: Prevalence of metabolic syndrome in selected adult African, South African and developed countries

Reference	Criteria used	Study design	n	Age (years)*	Country (ethnicity)	Male (%)	Female (%)
Studies of developed nations							
Aguilar et al., 2015 (93)	NCEP/ AHA	National Health and Nutrition Examination Survey 2011–12 – Cross–sectional	1, 931	≥20	USA (mixed, but no Asians)	32.8	36.6
Khan and Jackson, 2015 (94)	Harmonized method	Cross–sectional	1, 403	20–68	USA (South Asian Americans)	47.0	54.0
Cameron et al., 2009 (95)	IDF	Cross–sectional	6, 072	50.5 ± 11.7	Australia (White)	39.2	27.9
Salminen et al., 2011 (96)	IDF	Follow–up	1, 260		Finland (White)	37.0	63.0
Studies of developing non–African countries							
Kim, 2015 (97)	NCEP	Cross–sectional	11, 810	≥45	South Korea (Asians)	53.2	35.7
Fan et al., 2005 (98)	NCEP–ATP III	Cross–sectional	3, 175	52.4 ± 15.1	Shanghai, China (Asian)	22.9	20.8
Gupta et al., 2004 (99)	NCEP	Cross–sectional	1, 091	>20	North Indian (Asian)	22.9	39.9
Bhowmik et al., 2015 (100)	IDF	Cross–sectional	2, 293	≥20	Bangladesh (Asian)	19.2	27.5
Ozsahin et al., 2004 (101)	ATP III	Cross–sectional	1, 637	20–79	Adana, Turkey (Middle Eastern)	23.7	39.1
Al–Lawati et al., 2003 (102)	NCEP–ATP III	Cross–sectional	1, 419	>20	Oman (Middle Eastern)	19.5	23.0
Chu and Moy, 2013 (103)	NCEP–ATP III	Cross–sectional	219	45.9 ± 6.5	Kuala Lumpur, Malaysia (Asian)	37.1	24.2
Studies of African populations							
Akintunde et al., 2011 (104)	IDF	Cross–sectional	140	55.1 ± 10.8	Osogbo, Nigeria (black African	23	37
Tran et al., 2012 (105)	IDF	Cross–sectional	1, 935	≥24	Addis Ababa, Ethiopia (black African)	14.0	24.0
Assah et al.,	NCEP–ATP	Cross–sectional	552	25–55	Cameroon (black	7.0	25.0

2011 (106)	III				African)		
Balti et al., 2013 (107)	Harmonized	Cross–sectional	33	61.9 ± 29.9	Cameroon (black African)	50.0	71.0
Kenge et al., 2012 (108)	IDF	Cross–sectional	308	55.8 ± 10.5	Cameroon (black African)	58.0	86.1
Garrido et al., 2009 (109)	ATP III	Cross–sectional	51	39.2 ± 11.1	Botswana (black African)	15.9	24.5
Adeoye et al., 2015 (110)	IDF	Cross–sectional	256	42.0 ± 9.4	Nigeria (black African)	17.0	14.0
Ipadeola and Adeleye, 2015 (111)	IDF	Cross–sectional	340	>40	Nigeria (black African)	2.4	34.9
Labhardt et al., 2014 (112)	IDF	Cross–sectional	1, 026	≥25	Lesotho (black African)	9.8	22.9
Mogre et al., 2014 (113)	IDF	Cross–sectional	200	≥30	Ghana (black African	13.0	27.3
South African studies							
Crowther and Norris, 2012 (4)	Harmonized	Cross–sectional	1, 251	40.0 ± 10.6	Soweto, Johannesburg (black South African)	–	42.1
Schutte and Olckers, 2007 (114)	IDF	Cross–sectional	102	31.3 ± 8.6	Potchestroom, North–west province (black South African)	–	24.8
Jennings et al., 2008 (87)	IDF	Cross–sectional	225	27.0 ± 7.0	Cape Town (black South African)	–	9.9
Ntyintyane et al., 2007 (8)	IDF	Cross–sectional	23	51.1 ± 8.8	Johannesburg (black South African)	51.5	85.7
Motala et al., 2011 (7)	IDF	Cross–sectional	947	>15	Kwa–Zulu Natal (black South African)	11.2	21.2
Kalk and Joffe, 2008 (115)	IDF	Cross–sectional	500	>30	Black South African	46.5	52.9
Peer et al., 2015 (116)	Harmonized	Cross–sectional	1, 099	25–74	Cape Town (black South African)	16.5	43.0
George et al., 2013 (117)	Harmonized	Cross–sectional	373	41.6 ± 13.1	Soweto, Johannesburg (black South African)	–	29.2
Erasmus et al., 2012(118)	IDF	Cross–sectional	563	50.9 ± 9.1	Bellville, Cape Town (mixed ethnic background)	30.6	67.8

* Age range or mean age of participants as provided by the respective journal articles, National Cholesterol Education Program (NCEP); Adult Treatment Panel III (ATP); World Health Organisation (WHO); American Heart Association (AHA); International Diabetes Federation (IDF)

1.4.4 Anthropometric and metabolic risk factors for metabolic syndrome

Metabolic syndrome is composed of a collection of interconnected cardiometabolic diseases, which together increase the risk of type 2 diabetes and cardiovascular disease (16, 20). The presence of multiple metabolic disease states in individuals could indicate the possibility of an interrelationship between components of the syndrome and that there may be a shared predisposing factor for the various individual elements of the syndrome (80, 119).

1.4.4.1 Anthropometric risk factors for metabolic syndrome

The major areas of fat deposition are visceral and subcutaneous compartments of the body (120). Visceral adipose tissue seems to be more closely linked with cardiometabolic diseases compared with subcutaneous (121). The visceral fat deposit (indicated by central obesity/waist circumference) and ectopic sites are the preferred region of lipid uptake in higher BMIs (120, 122). This is confirmed by the evidence that obese women have significantly higher levels of visceral fat and insulin resistance compared with lean women (90). In a study of black South African women visceral obesity was shown to be the main driver of the high prevalence of metabolic syndrome (4). Other studies have shown that black South African (and African American) women have lower visceral adipose tissue and greater peripheral subcutaneous adipose tissue compared with white counterparts (90-92). The link between metabolic syndrome and visceral adiposity is confirmed in other African populations (18, 111), and in Australian and Mauritian cohorts (123). The mechanism through which visceral adiposity increases the risk of metabolic syndrome is through the sustained consumption of excess dietary lipids and the resultant reduced performance of insulin receptors. The uptake of lipids in the visceral compartment is enhanced by high serum insulin concentrations (124). Visceral adipose tissue increases in size and amount by

hypertrophy and hyperplasia respectively. This releases TNF–α and IL–6, insulin antagonistic adipokines, resulting in impaired insulin sensitivity (124). Over time the visceral adipose tissue loses its ability to function optimally, progressively leading to the metabolic syndrome (121). Moreover, visceral adipose tissue is associated with development of elevated systolic blood pressure (125), while a decrease in visceral fat was associated with improved fasting glucose and lipid profiles in a longitudinal study (126). These data confirm the importance of visceral adipose tissue in the aetiology of the metabolic syndrome.

In contrast, the subcutaneous adipose tissue compartment is relatively larger than the visceral depot and is composed of the truncal and gluteofemoral regions. The former region is heavier than the gluteofemoral region, and is associated with type 2 diabetes (127, 128), thus may provide a greater risk of metabolic syndrome in comparison. In fact, adipose tissue in the gluteofemoral region functions as a chronic metabolic bank of free fatty acid (FFA) storage, thus lowering ectopic adiposity (122, 129). In addition, studies have shown that gluteofemoral adipose tissue has been shown to increase HDL and lower total and low–density lipoprotein (LDL) cholesterol (130-132). Finally, although studies emphasise the contribution of upper body adiposity in the aetiology of the metabolic syndrome, the importance of gluteofemoral fat as a protective mechanism should not be ignored. Grundy et al. observed that lower truncal:body fat ratio is associated with lower risk of metabolic syndrome, particularly with regards to improving HDL levels, lowering serum triglycerides, and systolic blood pressure and reducing insulin resistance (133). Similarly, Goodpaster et al. observed a negative association between subcutaneous fat in the thigh region and metabolic syndrome (134).

1.4.4.1.1 Lean mass and metabolic syndrome

A number of age–related changes contribute to sarcopenia, a phenomenon which is associated with the decline of muscle mass and an increase in muscle weakness (135, 136). Studies of African and American women have also shown evidence of sarcopenia during the menopausal transition and its link to components of the metabolic syndrome (137, 138). These studies suggest that women experiencing menopause may have a higher level of fat deposition in relation to fat–free muscle mass. The increase in sarcopenia is also linked to

lower resting metabolic rate as people age, indicating the importance of maintaining strength type physical activity throughout the lifespan (139). Sustaining regular resistance training is particularly important as the effects of sarcopenia are gradually increased after the age of 30, but the decline in muscle mass accelerates rapidly after 50 years of age by approximately 10 to 15 % (140).

Studies have shown that premature progression of sarcopenia can be delayed by participation in a regimen of habitual physical activity (141, 142) during the ageing process by increasing the muscular force of the musculature (143). Therefore, the pattern of physical dysfunction and increased obesity can be reversed with exercise, especially when focussed on increasing the site–specific strength of the large musculature involved with functionality. The inclusion of habitual moderate–vigorous physical activity can also lead to a reduced risk of cardiometabolic diseases in older subjects (144).

A study of older individuals has shown that those with sarcopenia and excess adiposity have a higher risk of insulin resistance and associated co–morbid diseases compared with those in the non–sarcopenic lean, non–sarcopenic non–obese, or sarcopenic non–obese groups (145). A Japanese study of healthy women, showed similar associations between sarcopenia and cardiovascular diseases (146). Both cross–sectional and longitudinal studies show that women who have transitioned into menopause have lower levels of fat–free, soft–tissue mass and higher fat mass values compared with pre–menopausal women (137, 138, 147). This evidence suggests that women in the post–menopausal category are at more risk of metabolic syndrome compared with those who are pre–menopausal. In support of these facts, other studies have shown that decreased lean muscle mass increases the risk of metabolic syndrome in adults (148-151).

Sarcopenia also seems to be associated with increased risk of hypertension (152), low HDL levels (153), high cholesterol levels (154), type 2 diabetes (155), and the accumulation of fatty deposits in the visceral region (156). Therefore, the increasing prevalence of obesity and metabolic syndrome in African women could be linked to the progressive changes in

muscle architecture imposed by the complex ageing process, suggesting a potential role for lower lean muscle mass in the development of metabolic syndrome.

1.4.4.2 Metabolic risk factors for metabolic syndrome

1.4.4.2.1 Insulin resistance

Postprandial normoglycaemia is maintained in insulin–sensitive subjects by the release of insulin. In contrast, in those individuals with insulin resistance, pancreatic islet β–cells produce excess amounts of insulin for glucose uptake, while hepatic production of glucose fails to be suppressed (157). Chronic dysfunction of the pancreatic islet β–cells results in depletion of insulin in this reserve because of higher metabolic demand in insulin resistance (158).

The aetiology of insulin resistance is multifaceted, but a fundamental feature of this condition is the inability of plasma insulin to suppress hyperglycaemia (159). Insulin resistance has been linked with the onset of metabolic syndrome (15), however, the components of metabolic syndrome can develop independent of insulin resistance (12). The main feature of insulin resistance is a disruption in the normal glucose homeostasis (80), resulting in a high concentration blood glucose and ineffective plasma insulin. Sustained hyperglycaemia stimulates an increased risk for diabetes–associated disorders such as neuropathies (48). Conversely, approximately 30 % of people diagnosed with metabolic syndrome have normal insulin functionality (80). The involvement of insulin resistance in the progression towards metabolic syndrome is debatable, but evidence has shown that obesity precedes the development of other components of metabolic syndrome (160). In contrast, a study of type 2 diabetics observed no association between insulin resistance and the components of metabolic syndrome (161), which could possibly be explained by the existence of diabetes (162).

Obesity has a positive association with insulin resistance and directly influences metabolic syndrome risk (20), and can subsequently result in biochemical and endocrine abnormalities. Whole body adiposity is the main contributor of insulin resistance at lower BMIs as this

region is more insulin sensitive compared with the visceral depot and therefore will accumulate more lipid (163). However, as BMI increases, the accumulation of lipids in the subcutaneous fat region reduces as the factors controlling insulin sensitivity suppress triglyceride accumulation (164). The visceral fat deposit (indicated by waist circumference) and ectopic sites subsequently become the preferred region of lipid uptake at higher BMIs (120, 122). This is confirmed by the evidence that obese women have significantly higher levels of visceral fat and insulin resistance compared with lean women (90). With increasing waist circumference, black South African women also accumulate less visceral adipose tissue compared with white women (92).

Ectopic fat deposition in skeletal muscle, liver and other organs is associated with insulin resistance (165) and the metabolic syndrome (166). The underlying reason is thought to be related to an excess consumption of energy–rich foods in the diet, which results in a 'spill–over' lipid storage effect, from the various adipose tissue compartments to the organs and skeletal musculature. A meta–analysis and systematic review found that the fat in the epicardial region was much thicker in those with metabolic syndrome compared with those subjects without metabolic syndrome (167). Epicardial fat was also associated with the individual components of the syndrome, but showed a greater association with BMI, waist circumference and visceral adiposity. Similarly, ectopic fat in the liver is also associated with metabolic syndrome and its components (168).

Insulin resistance can also be influenced by adiponectin (164), mainly by the action of this adipokine on insulin function (169). The level of adiponectin is modulated by visceral adipose tissue. Thus as the visceral compartment reduces, the concentration of adiponectin increases, and subsequently improves insulin sensitivity in subjects (170). Conversely, lower levels of adiponectin are associated with insulin resistance (171). Administration of endogenous adiponectin in those subjects diagnosed with insulin resistance has been shown to improve insulin sensitivity (172). These data show that adiponectin may have an important influence on key metabolic diseases associated with metabolic syndrome.

1.4.4.2.2 Adipokines and inflammatory factors

Adipose tissue is not simply a passive reservoir for lipids as previously thought (164). In response to afferent signals, this endocrine organ secretes adipokines which function at the local and endocrine level. In conditions of excess adiposity, these adipokines are associated with an increased risk of cardiometabolic diseases such as insulin resistance and hypertension (170, 173). Some of these adipokines are linked to metabolic syndrome and will be discussed below.

1.4.4.2.2.1 Adiponectin

Adiponectin is one such protein implicated in metabolic diseases (164), and seems to be one of the main factors in the relationship between fat accumulation and insulin resistance (174). The concentration of plasma adiponectin is significantly lower in obese subjects and those who present with type 2 diabetes (175). Evidence has also confirmed that adiponectin modulates insulin sensitivity (169). A lower concentration is therefore linked with insulin resistance, particularly as visceral fat increases (170). The secretion of adiponectin from the visceral compartment seems to be higher compared with subcutaneous fat in non–obese subjects, however as BMI increases the secretion of adiponectin from this region decreases (176). The in–vitro treatment of isolated human adipocytes with insulin resulted in increased adiponectin secretion from adipocytes isolated from the visceral deport but not from those taken from the subcutaneous region (176). This suggests that improved insulin sensitivity is enhanced by increased secretion of adiponectin from the visceral region rather than the subcutaneous region.

In a longitudinal study of the Pima Indians of Arizona, USA, findings showed that hypoadiponectemia was associated with obesity and insulin resistance (171), while hyperadiponectemia showed a protective, independent effect against the onset of type 2 diabetes (177). Higher concentrations of adiponectin correlate with lower BMI and higher insulin sensitivity in a combined sample of different South African population groups, however Caucasian subjects had higher levels of adiponectin compared with the other ethnic groups (33). Few data are available on the role of adiponectin in the aetiology of metabolic

syndrome in developing countries (178), but studies of African populations suggest a protective role of adiponectin against metabolic syndrome (33, 179). Finally, evidence suggests an association of low adiponectin concentration with individual components of metabolic syndrome and the syndrome itself (180-182).

1.4.4.2.2.2 Leptin

Leptin is another adipokine which is positively associated with fat accumulation. As adipose tissue increases in mass, leptin concentration increases to suppress satiety via the hypothalamus (157). In animal studies, the administration of leptin to lean and leptin–deficient obese mice resulted in a reduction in food intake (183). This indicates that leptin is able to suppress hunger rapidly during normal biological conditions. Fat accumulation is associated with increased concentrations of plasma leptin in humans, whilst a decrease in body weight following the control of dietary intake is associated with lower levels of plasma leptin in humans and mice (184).

The majority of obese subjects are not deficient in leptin and demonstrate higher levels of leptin compared with leaner individuals (185), implying the decreased appetite–suppressing effects of leptin or increased leptin resistance in obese individuals. Leptin resistance may be due to impairment of the leptin transporter system in the brain rather than mere saturation due to higher levels of circulating leptin (186).

In a South African cross–sectional study, leptin concentrations were higher in black African women with known coronary artery disease compared with matched males, and an association with metabolic syndrome was demonstrated (173). In other South African studies, leptin correlates with insulin resistance and central adiposity, variables which seem to be fundamental to the metabolic syndrome (187, 188). There also seems to be ethnic differences in leptin concentration of South African women. For example, white South African women have lower leptin levels compared with BMI–matched black women (189). Leptin concentrations were shown to be higher in obese black South African women compared with obese white women at fasting and glucose loading periods, indicating an

ethnic variation in the metabolism of adipocytokines (190). A relationship between high leptin concentration and the other components of metabolic syndrome has been observed in South African studies. The positive association between leptin and blood pressure in black South African women was shown in various South African studies (191-193), while leptin does not seem to correlate with total or LDL cholesterol in patients with diagnosed familial hypercholesterolemia (FH) and CAD (194) . The latter needs to be confirmed in African women without FH.

1.4.4.2.2.3 Inflammatory factors

Metabolic syndrome seems to be associated with certain inflammatory markers (85). C–reactive protein (CRP) and interleukins have been found to have an association with metabolic syndrome in Chinese subjects (195), however some studies have only confirmed the relationship between CRP and metabolic syndrome in women (196), while others show no association between interleukins, tissue necrosis factor–α and the metabolic syndrome (197). Similarly, studies have observed the relationships of resistin (198), vaspin gene expression (199), retinol–binding protein 4 (200) with the metabolic syndrome. However the role of inflammatory markers in the pathogenesis of obesity–related disorders and metabolic syndrome is controversial (201). Nevertheless, the secretion of CRP by the liver is stimulated by adipokines during the expansion of adipose compartments in the visceral region, suggesting that this inflammatory marker may be an important predictor of the development of type 2 diabetes and metabolic syndrome in subjects at risk (80). Thus, further research is required to confirm the association of inflammatory markers with metabolic syndrome and its components.

1.5 Shared risk factors for obesity and metabolic syndrome

Obesity and metabolic syndrome are complex and multi–faceted diseases. A number of the underlying risk factors are shared. This section explores whether these common risk factors lead to metabolic disease because of obesity or whether they act directly to cause disease, or whether it is a combination of both.

1.5.1 Physical inactivity and sedentary behaviour in developing countries

Physical inactivity is an important environmental risk associated with chronic diseases. Recent WHO estimates show that insufficient activity is responsible for 3.2 million deaths globally (202). Data on the physical activity patterns of people living in developing countries are sparse (21), however, data from South America imply that physical inactivity in the lower SES strata has increased over time (203). This suggests that there may be a regional shift in the pattern of physical activity in certain developing countries. A recent cross–sectional study showed that physical activity levels did not vary significantly in different regional settings, and there was an inverse correlation between moderate–vigorous physical activity (MVPA) and SES characteristics in higher income countries and LMICs (204). The relationship between SES and physical activity was largely due to increased vehicle ownership across different SES groups, indicating that increasing global access to motor vehicles and other labour-saving devices might partly be the reason for the decline in activity and the subsequent increased onset of chronic diseases and disabilities.

South Africa is the third most physically inactive country in Africa, and only 1.6 % less active than Namibia in second place (205). The consequence of such a high prevalence of physical inactivity is that black South African women rank in the top proportion of obesity prevalence in the African continent (2). In Cameroon, a sub–Saharan African country also experiencing epidemiological transition, rural dwelling people have demonstrated higher amounts of energy expenditure compared with urban dwellers (106). Those who presented with lower levels of physical activity were shown to have higher levels of metabolic syndrome, indicating the link between energy expenditure and cardiometabolic diseases. The economic cost related to insufficient physical activity ranges from 1 to 3 % of the total budget spent on healthcare in South Africa (206), however, reversing the situation remains challenging, especially in developing countries with limited resources (207).

1.5.1.1 The definition of physical activity

Physical activity is broadly defined as the voluntary movement of the body by the contraction of skeletal musculature, resulting in the expenditure of energy (48). The WHO formulated the global physical activity questionnaire (GPAQ) for the investigation of physical activity patterns of populations around the world (208). The recommendations for physical activity from GPAQ include: moderate physical activity for a total of 150 minutes per week (≥5 days per week); or vigorous physical activity for 60 minutes per week (≥3 days per week); or 600 metabolic minutes per week [≥5 days moderate-vigorous physical activity (MVPA)] (209). The tool was formulated as part of the World Health Organisation STEPwise approach to Surveillance initiative to help LMICs collect data on chronic diseases and physical activity, but is now commonly used around the world and has produced a substantial amount of research on the worldwide patterns of physical activity (21). Accomplishing the recommendations for energy expenditure ensures that health is improved or maintained, and lowers the risk of mortality related with metabolic syndrome (205). However, citizens of most countries around the world are insufficiently active, and only a small percentage are actively involved in regular, moderate–vigorous physical activity (210).

1.5.1.2 Different domains of physical activity in developing countries

It was previously thought that physical activity was higher in high income countries (210), but emerging evidence suggests that the pattern of physical activity is improving in LMICs (202). This seems to be mostly as a result of greater time spent walking as a means of transport and high amounts of physical activity during work time. In comparison, people in higher income countries typically accumulate total weekly physical activity from recreation or leisure time activities (211). This indicates that as people's wealth increases, there seems to be a shift towards participating in more leisure time physical activity (212). The available data on African populations shows evidence of regional variation in the pattern of physical activity (213). For instance, in some African countries such as Eritrea and Mali total energy expenditure is mostly driven by active commuting, while in other countries in the African region most of the daily physical activity is performed in the work domain (213). Black South African women seem to accumulate most of their weekly physical activity in the

walking for transport domain (214, 215). The Transition and Health during Urbanisation of South Africans (THUSA) study showed that most of the participants were insufficiently physically active (28). A third of the sample who were sufficiently active accumulated physical activity in walking for travel and work domains. The THUSA study also showed that physical inactivity posed a higher risk of fat accumulation compared with nutritional status or SES.

1.5.1.3 Walking as a means of transport

Active commuting by walking is associated with better health outcomes, and walking for longer durations has been inversely associated with blood pressure and type 2 diabetes (216), indicating that walking for transport may lower the risk of metabolic diseases if sustained. However, data suggest that this form of activity should be performed at a brisk pace in order to gain optimal cardiometabolic health benefits (217-219).

In rural South Africa, most women walk more than the recommended 10,000 accumulated daily steps, resulting in a low risk of excess fat accumulation (220). Women in urban South Africa demonstrate lower accumulated time spent walking and a higher prevalence of obesity compared with women in rural settings (2, 220). Studies have shown that less than thirty minutes of accumulated moderate intensity physical activity or brisk walking do not result in any significant decrease in the future risk of stroke or hyperglycaemia (221, 222), whilst other studies widely support the benefit of higher amounts of accumulated energy expenditure for the prevention of cardiovascular diseases (28, 32, 41, 106, 223, 224). These data suggest that more than 30 minutes per day of moderate intensity physical activity are needed for optimal prevention of cardiometabolic diseases. Recent pooled data (2015) from various middle income countries indicated that those who performed ≥150 minutes per week of active walking for transport had better outcomes in terms of waist circumference; BMI and systolic blood pressure (225). This implies that even though people in LMICs predominantly engage in non–recreation related physical activity, the same potential for disease prevention observed in higher income countries from increased recreation physical activity can still be achieved by increasing time performed in walking for transport.

1.5.1.4 Sedentary behaviour

Time engaged in sedentary activity is strongly related to the onset of cardiovascular diseases (226), with data showing that, as sedentary time increases, so the risk of all–cause mortality increases, even after adjustment for time spent expending energy (227). This indicates that, the risk of cardiovascular diseases may still be a threat because of extended sedentary time, despite a relatively high duration of moderate–vigorous activity. Sedentary behaviour can be defined roughly as the failure to significantly increase energy expenditure above resting metabolic levels (228). On the other hand, the Sedentary Behaviour Research Network's definition for sedentary time describes that sedentary time is time spent sitting during waking hours, particularly a metabolic equivalent (MET) level of "energy expenditure ≤1.5 METs whilst in the sitting or reclining position" (229). Extended time in sedentary activities can increase the risk of obesity because these activities do not allow for a negative energy balance threshold to be reached (230, 231). Most of these sedentary activities are certainly everyday activities, but these data imply that additional, more intense physical activity (>1.5 METs) is necessary for the maintenance of disease prevention.

Available data of sedentary behaviour shows that there are differences in the amount of sitting time in developing versus higher income countries. In LMICs such as Brazil, China, and India, sitting time is reported at an average of 210 sitting minutes per day (232). In comparison, developed countries such as Norway and Sweden display higher amounts of sitting time (an estimated average of 330 sitting minutes per day) (232), despite relatively lower levels of obese women compared with African countries (233). Nevertheless, longitudinal evidence does confirm there has been an increase in the prevalence of excess adiposity in Nordic women over the past few years and is projected to increase further (234). The higher level of sitting time in richer countries is related to better economic factors and a greater propensity for people owning sedentary–promoting assets such as motor vehicles and satellite television and increased television viewing time (235, 236). Vehicle ownership is associated with decreased physical activity time and increased risk of acute myocardial infarction (235, 236).

South Africans on average have a high level of sedentary time in the midst of increasing obesity and related diseases (23, 237), and the economic growth of the country has made the purchasing of sedentary–promoting assets more affordable for the large majority. The modern lifestyles of South African people are comparatively less energy–demanding than in the past when technology was not as advanced (40, 41). As a result of this lack of activity, sedentary behaviour is maintained without adequate expenditure of the ingested calories. Data from different South African population groups show that women living in urban settings have higher sitting times than urban men and women living in rural areas (32, 220, 224, 238-240). Data have shown that postmenopausal women who are involved in higher–intensity physical activity have a lower accumulation of adipose tissue in the visceral compartment compared with those who are sedentary or engage only in light physical activity (241). Recent South African data showed that black African women who met these physical activity guidelines at baseline presented with a lower risk of insulin resistance and high HDL levels at follow–up compared with less active women, despite total body weight having increased in both groups over a 5.5 year study period (214). In summary, these studies highlight that, while physical activity is associated with positive health outcomes and the reverse for sitting time, scientists are still investigating and trying to understand the physical activity patterns of those living in emerging nations (21), especially in black women from South Africa who have a high level of obesity and related diseases.

1.5.2 Diet

The higher prevalence of excess adiposity in black South African women compared with whites confirms that South Africa is in the advanced stages of the nutritional transition (242). The emergence of metabolic diseases associated with metabolic syndrome in South Africans could be attributable to the adoption of lifestyle behaviour associated with nutritional transition (237), with those in the lower SES stratum consuming cheaper, energy–dense foods, predominantly purchased from informal street food vendors (243). Such excessive caloric intake could be associated with the high prevalence of obesity in black African women (122). Preference for higher caloric intake might also be explained by a general acceptance of larger body–size in African populations (76).

Studies have shown that black children and adolescents in South Africa are not reaching the recommended daily allowance for energy intake (244-247). In comparison, urban black adult African women are receiving enough dietary energy intake, but mostly from refined carbohydrates (248). A diet high in carbohydrates is associated with atherogenic dyslipidaemia (249), particularly a lowered HDL concentration and increasing serum triglyceride concentration (250). Moreover, African populations do not consume sufficient fruits and vegetables (251), and compared with rural black African women, urban–dwelling women consume more total fat, saturated fat and sugar (23, 252).

It was recently shown that even though the wealth of developing and developed countries differs vastly, the economic differences between the socio–economic classes in these countries is wide and has an influence on the outcome of cardiometabolic disease risk (253). The availability of healthy food is sparser in the poorer communities while the rich have a much broader selection of quality foods. This indicates that the problem of unhealthy eating associated with obesity can be alleviated by reducing the food inequality imposed by economic circumstances.

1.5.3 Age

Ageing is associated with the natural, progressive loss of physiological function of approximately 2 % per annum in healthy adults (254). The prevalence of metabolic syndrome seems to be positively associated with ageing in most communities around the world (53, 99, 255, 256). The reason for the relatively linear relationship of age with metabolic syndrome and its components is linked to the age–related increases in resting systolic blood pressures and glucose levels (257). Individuals who are older seem to have lower end–diastolic volumes compared with younger people (258), whilst diastolic function declines with increasing age (259). Nevertheless, the influence of systolic dysfunction has a greater impact on metabolic syndrome in ageing subjects compared with diastolic blood pressure. This is confirmed by the linear relationship between systolic blood pressure and metabolic syndrome, while diastolic blood pressure does not correlate with the syndrome (257).

The presence of type 2 diabetes and high fasting glucose levels seems to increase with age, independent of BMI (257). Interestingly, Gabriely observed that as visceral fat accumulates with ageing, the regulation of blood glucose progressively deteriorates, indicating that the visceral compartment is a better indicator of diabetes risk in older subjects compared with BMI (260). Moreover, even though fat mass accumulates in both visceral and subcutaneous compartments with age, the quality and functionality of adipose tissue only in the visceral region declines with age (261).

1.5.4 Socio–economic status and education

People in the lower socio–economic stratum are universally faced with health inequality and multiple deprivations (262). Socio–economic status (SES) is a complex and multifaceted notion, having being defined by Bollen *et al.* (1999) as signifying

> the position of individuals, families, households, or other aggregates on one or more dimensions of stratification. These dimensions include income, education, prestige, wealth, or other aspects of standing that the members of society deem salient (263).

Evidence from studies shows that lower SES is associated with a higher number of negative health outcomes (264, 265), however, between–country analyses show that the relationship between SES and BMI is not consistent (266). For instance, in the richer, developed regions of the world, SES has an inverse relationship with BMI (267); however, in LMICs, the relationship between SES and BMI is uncertain. For example, national surveys performed in low–income Latin American countries showed that higher SES correlated with higher levels of BMI (268-270). In contrast, in the comparatively higher income Latin American country of Mexico, the relationship between obesity and SES appears to be negative (271). In South Africa (26, 76, 272) and other countries in sub–Saharan Africa (273, 274), the relationship between obesity and SES has constantly been shown to be positive. During the apartheid era the black majority were predominantly in the lower SES groups and have historically been marginalised by limited access to education, healthcare, and the ability to earn a sustainable income (28, 275, 276). They were generally living in poverty in segregated regions. The

impact of SES as a potential contributor of metabolic disease outcomes in the South African context is therefore important to consider.

Even in the post–apartheid era, the majority of black people are still living in relatively poorer conditions compared with other population groups, with most not having completed high school (2). Recently published data on poverty trends in South Africa demonstrated that the income of black African groups increased by 35.4 % from 2006 to 2011 compared with 0.4 % in white–headed households; however, 40.3 % of black–headed households were living in poverty in 2011 and there are still disparities in the social assistance system of South Africa (277). Lower SES groups bear the greatest burden of diseases of disability and ill health in South Africa, and the prevalence of the individual metabolic syndrome components is now also increasing in the poor and not just among the more affluent white population (278).

Over two–thirds of black Africans (66.8 %) were in the upper portion of poverty in 2006, unchanging in 2009 (66.9 %), and then decreasing to just over half of the group (54 %) in 2011 (277). In terms of access to quality healthcare, only 10.8 % of black Africans were on medical aid schemes in 2013 (279). Likewise, only 3.2 % of adult black Africans (between 18 and 29 years old) were studying in higher education institutions in the same year (279).

The variation in overweight and obesity prevalence between white and black African groups could in part be the result of the disparities between ethnic groups emanating from the pre–1994 era (280), however, these disparities still exist in 2015. In addition, education has been found to have a positive association with BMI, independent of SES in the sub–Saharan African region (26, 76, 272-274), however previous studies in LMICs have observed that education is negatively correlated with BMI in urban settings, whereas, in rural regions, the relationship with obesity is direct or non–linear (270, 281). Data from the South African demographic and health survey of 2003 shows that men and women with some form of schooling have higher BMI values than those who have not attended school or tertiary education (282).

1.5.5 Smoking, and smokeless tobacco

Cardiovascular diseases are significantly increased with smoking, independent of age, gender or body composition; however, in active smokers with metabolic syndrome, the cardiovascular disease risk is two times higher than that of those without metabolic syndrome who smoke, and nearly six times higher than those non–smokers with metabolic syndrome (283). There also seems to be a dose–dependent relationship between tobacco consumption and risk of cardiometabolic diseases (284), suggesting that as the frequency of cigarette smoking increases so does the potential for metabolic syndrome. Tobacco consumption in South Africans is relatively high in black males, and in comparison with other population groups, black South African women have a significantly lower prevalence of active smoking (23).

Active smoking provides comparatively higher risks for cardiovascular diseases compared with other risk factors. This can be explained by a number of potential pathways. The hypothalamic–pituitary–adrenal axis production of plasma cortisol is associated with active smoking (285). Cortisol is insulin antagonistic and increased levels disrupt normal glucose metabolism, resulting in increased lipolysis and elevated plasma glucose concentration (286). In active smokers, the basal concentration of plasma insulin is high, independent of other factors contributing to lower insulin sensitivity (287). Therefore, prolonged hypersecretion of cortisol in chronic active smokers increases the risk of type 2 diabetes (288), but seems to diminish substantially after cessation (289). The concentration of plasma cortisol is also higher during the day in habitual smokers compared with non–smokers (290).

Smoking is also associated with an increased visceral fat accumulation, evident by a higher waist circumference in active smokers compared with non–smokers (291). This is influenced by a higher plasma concentration of cortisol as a result of increased sympathetic nervous system activation (292). In addition to tobacco consumption resulting in high basal plasma cortisol concentrations, female smokers were previously observed to have an increased androgen:estrogen ratio (293), while in male active smokers, visceral fat accumulation is increased due to lower testosterone levels (294). This clarifies the strong association of

tobacco consumption with lower insulin sensitivity (295-297), and the risk of type 2 diabetes (288). However, the appetite suppressing qualities of nicotine are well known. People who actively smoke gain less total body fat over time and have a lower total body fat mass in comparison with non–smokers, and cessation of smoking is strongly linked to acute fat accumulation (298).

Active smoking also increases endothelial dysfunction by decreasing the production of endothelial nitrous oxide, which is responsible for vessel integrity (299). Chronic exposure to tobacco smoke also reduces contractility of the arterial wall (300), increases the risk of non–calcified plaques (301), and thrombotic platelet formation in the lumen of vessels (302). Thus, smoking cessation not only reduces the risk of chronic elevated blood pressure, but also lowers the risk of atherosclerosis.

The consumption of smokeless tobacco (snuff) is comparatively more popular than cigarette smoking among black South African women (303). Oral snuff is addictive and the concentrations of carcinogenic tobacco–specific N–nitrosamines (TSNAs) and nicotine in snuff products from countries around the world are high (304). South African snuff has a lower concentration of TSNAs compared with the majority of products from other countries, but the amount of unionised nicotine in the products is high (304). Unionising nicotine allows for faster absorption rates of nicotine, independent of the preferred method of consumption. The relative risk of cardiovascular disease mortality for users of smokeless tobacco is not as high as cigarette smoking (305, 306), while studies have shown that snuff use is not associated with an increased risk of myocardial infarction (307) or stroke (308).

The relationship between the use of snuff and type 2 diabetes is unclear. For example, in one study, smokeless tobacco was shown to be associated with type 2 diabetes in a dose–dependent manner (309), while in another study no relationship between these variables was observed, even after taking into account environmental factors (physical inactivity and excessive alcohol consumption) (310). The relationship between snuff and dyslipidaemia is similarly unclear. Higher total cholesterol levels were noted in users of smokeless tobacco

compared with non–users (311) while in another study, no significant differences were demonstrated (312).

In summary, these studies show that the association of smokeless tobacco with cardiometabolic factors seems to be unclear even though the consumption of smokeless tobacco has previously been associated with increased fat deposition in the visceral region (137). A study has also shown a relationship between smokeless tobacco and metabolic syndrome (313), but this needs to be tested in the African context.

1.5.6 Alcohol consumption

Various gastrointestinal diseases and cancers have been associated with the abuse of alcohol (314, 315). Alcohol abuse is also associated with the onset of cardiometabolic diseases, and nearly 6 % of all global deaths in 2012 were related to alcohol (202). In contrast, it seems that a low–to–moderate consumption of alcohol reduces the risk of coronary artery disease by approximately 20 %, while the risk increases significantly if alcohol consumption exceeds 90 grams per day (316). Moderate consumption of alcohol also seems to protect against the development of diabetes and sudden cardiac arrest in diabetic patients (317).

The acute consumption of alcohol increases insulin resistance in the skeletal musculature, possibly mediated by decreasing hepatic glutathione or hepatic–insulin sensitising substance (318). Studies demonstrate that the frequency of alcohol consumption is inversely associated with BMI (319, 320), while intermittent bouts of excessive alcohol consumption such as binge drinking are associated with higher waist circumference (321). Epidemiological studies have shown that alcohol seems to be particularly more protective against weight gain in women compared with men (322). In support of these findings, a longitudinal study demonstrated that the frequency of alcohol consumption is inversely associated with central adiposity, independent of gender, age, physical activity level, tobacco use, baseline waist circumference, type or amount of alcoholic beverage consumed, or socioeconomic status (323). The protective effect of alcohol against increasing waist circumference in non–binge

or frequent drinkers can be explained by increased thermogenesis, modulated by alcohol dehydrogenase and the microsomal ethanol–oxidising system functionality, effectively metabolising alcohol in the body (324).

South Africans have a moderate consumption of alcohol in relation to other countries, and evidence shows that alcohol consumption increases linearly as wealth improves (202). This indicates that there may be a relationship between SES and the consumption of alcohol. More South African men consume alcohol than women, and there are more urban–dwelling people indulging in health debilitating drinking activities compared with rural dwelling people (23). In comparison with other ethnic groups, black male Africans are more likely to participate in binge drinking activity (325).

1.6 Metabolic syndrome and its link with increased risk of future chronic diseases

The significance of the metabolic syndrome as a predictor of future chronic diseases or as a risk factor for cardiovascular disease is controversial (326). Apart from the deleterious effects of the components that make up the clustered syndrome on the circulatory system, a number of studies have observed that type 2 diabetes and cardiovascular disease are associated with metabolic syndrome (327-331). However, the finding that metabolic syndrome is associated with future risk of type 2 diabetes is not surprising as many of the definitions of metabolic syndrome have impaired fasting glucose included as a criteria (20). Similarly, the finding that metabolic syndrome increased the risk for CVD in some studies could be anticipated as the syndrome contains factors which increase the risk for CVD (328, 331). Established methods of modelling for type 2 diabetes (Diabetes Predicting Model) and CVD (Framingham Risk Score) were shown to be better predictors than metabolic syndrome in the San Antonio Heart longitudinal study (332). In contrast, a recent study of hypertensives showed that the metabolic syndrome, independent of its individual components, is a better predictor of future cardiovascular events compared with the Heartscore model, which is an established model of cardiovascular risk (333). In support of this, the findings from Gupta et al. show that metabolic syndrome has no effect on coronary outcomes, but increases the risk of future cerebrovascular events and all–cause mortality,

independent of its various components (334). It has also been observed that the risk of all–cause mortality and CVD morbidity are increased in hypertensive patients with the syndrome (335). Thus, even though it seems that metabolic syndrome can be a good predictor of future disease, some limitations are still evident. For example, the criteria used for diagnosis can be problematic: subjects may be diagnosed with metabolic syndrome that already have established diabetes or other co–morbid diseases, the usefulness of metabolic syndrome as a therapeutic/management tool is restricted, categorising of risk factors into a binary state rather using the original continuous variable, metabolic syndrome ascribes relative risk of disease rather than absolute risk (336).

1.7 Research gaps

The prevalence of obesity in developing countries is increasing, and is particularly high in urban, black South African women (2). Consequently, the incidence of metabolic syndrome is common in these women (4); however, few data are available on the risk factors associated with these diseases.

Urbanisation has been linked with the adoption of behavioural patterns associated with the development of excess adiposity (30). The rapid technological advances of the modern era and the on-going urbanisation taking place in developing countries have resulted in people expending less energy and sitting more compared with those in rural–settings (21, 337). However, few data are available on the physical activity patterns of people living in urban centres in LMICs.

Tobacco consumption is associated with visceral adiposity (291), and an inverse association between alcohol and fat accumulation has been demonstrated (323). Both of these behaviours are not common in South African women, nevertheless, few data are available on the association of smoking, alcohol consumption with cardiometabolic diseases in African populations. Evidence from the recent SANHANES shows that the consumption of smokeless tobacco is high in black South African women (23). Data on the relationship of smokeless tobacco and metabolic syndrome is conflicting, with some studies showing a relationship (313) and others not (338). The smokeless tobacco sold in South Africa has a higher nicotine absorption rate compared with products in other countries (304).

Traditional African cultural ideals regarding body–size preference favour women who are in the overweight/obese categories of body mass index (5). The propensity to follow these beliefs could also influence dietary habits and levels of physical activity. However, recent evidence suggests that traditional beliefs around body image are changing in young, black adolescent South African females (77, 78). This implies that adult black African women may also be experiencing acculturation of belief patterns, but there is a lack of data on the psycho-social factors associated with obesity in African populations.

Certain adipokines may have a potential role in the pathogenesis of metabolic syndrome (170, 173). Few studies have demonstrated a link between these compounds and cardiometabolic diseases in African populations.

Age is associated with the natural decline in lean muscle mass, and data suggests an association between lean mass and cardiometabolic diseases (339). The premature development of sarcopenia influenced by lack of physical activity and increased sitting time can increase the risk of developing cardiometabolic diseases (142), however this has not been studied in African populations.

There have not been any studies showing the interrelationship of risk factors in their association with metabolic syndrome in African populations. The principal risk factors for metabolic syndrome are not known in this population, especially so in urban African women where the prevalence of both obesity and metabolic syndrome are high (4).

1.8 Research question

My research question is:

What are the risk factors for obesity and metabolic syndrome in African women?

1.9 Objectives and hypotheses

Objectives

The specific objectives of this thesis were as follows:

1. To describe patterns of physical activity in a middle–aged cohort of urban black South African women living in Soweto, Johannesburg
2. To examine the association between socio–economic status and physical activity patterns
3. To determine if physical activity is associated with anthropometry and metabolic variables
4. To describe the change in body composition over a10–year study period in a cohort of urban black South African women.
5. To determine whether baseline measurements of body–size dissatisfaction and body–size discrepancy are associated with baseline body composition measures, and correlate with changes in body composition over 10–years of follow–up.
6. To determine whether baseline lifestyle factors including diet and physical activity are associated with changes in body composition
7. To identify the main contributing factors to the cardiometabolic features of the metabolic syndrome in a cohort of urban African women known to have a high prevalence of obesity and metabolic syndrome
8. To determine how disease risk varied across the range of levels of each risk factor
9. To examine whether each risk factor modulated the contribution of the other factors to disease risk across their range
10. To determine which individual components of the metabolic syndrome were influenced by each of the risk factors

Hypotheses

1. Urban, black South African women have a high prevalence of obesity and metabolic disease both of which are associated with physical inactivity.
2. Body–size perception and physical activity are associated with changes in body composition in black South African women. In an under-studied population with a high prevalence of cardiometabolic diseases novel risk factors for metabolic syndrome would be identified and that disease risk would vary across the range of these variables.

3. Physical activity in black South African women is high, but mostly as a result of the walking for transport domain of physical activity.
4. The majority of black South African women have a high amount of weekly sitting time, and this is related to high risk of metabolic syndrome.
5. In an under-studied population with a high prevalence of cardiometabolic diseases novel risk factors for metabolic syndrome would be identified and disease risk would vary across the range of these variables.
6. We also hypothesised that each risk factor for metabolic syndrome for metabolic syndrome would modify the contribution of the other factors to disease risk by varying degrees across their range.
7. We further hypothesised that each of these factors will influence metabolic syndrome risk by effects on individual components of the syndrome.

CHAPTER 2 – METHODOLOGY

2.1 Introduction

The methodology used for the collection of data for this PhD thesis will be outlined in this chapter. There were similarities in methodology in all of the studies, which are described in more detail in this chapter; however, any variation in the research methods for the respective studies will be discussed in the appropriate results chapters. English was used for administering the questionnaires, however, whenever specific questions were not understood, and the research assistants were available to assist with comprehension in the participants' home languages. Statistical methodologies for the different studies are described in detail in the respective results chapters.

2.2 Study setting – Soweto, Johannesburg

The Soweto metropolitan region is 15 kilometres southwest of Johannesburg's former business centre (Figure 2.1). The area was initially created as a separate district to accommodate the black African miners who worked in the surrounding gold mines (340). The region is now mostly populated by black South Africans, most of which are female, originate from the isiZulu ethnic group, and speak a native home language as well as conversational English (341). Approximately 40% of Johannesburg's total population reside in Soweto, and the 2011 census estimates the population size around 1.27 million. The total area of Soweto is 200 km^2 and includes 34 sub–districts with most houses having being built with bricks (340).

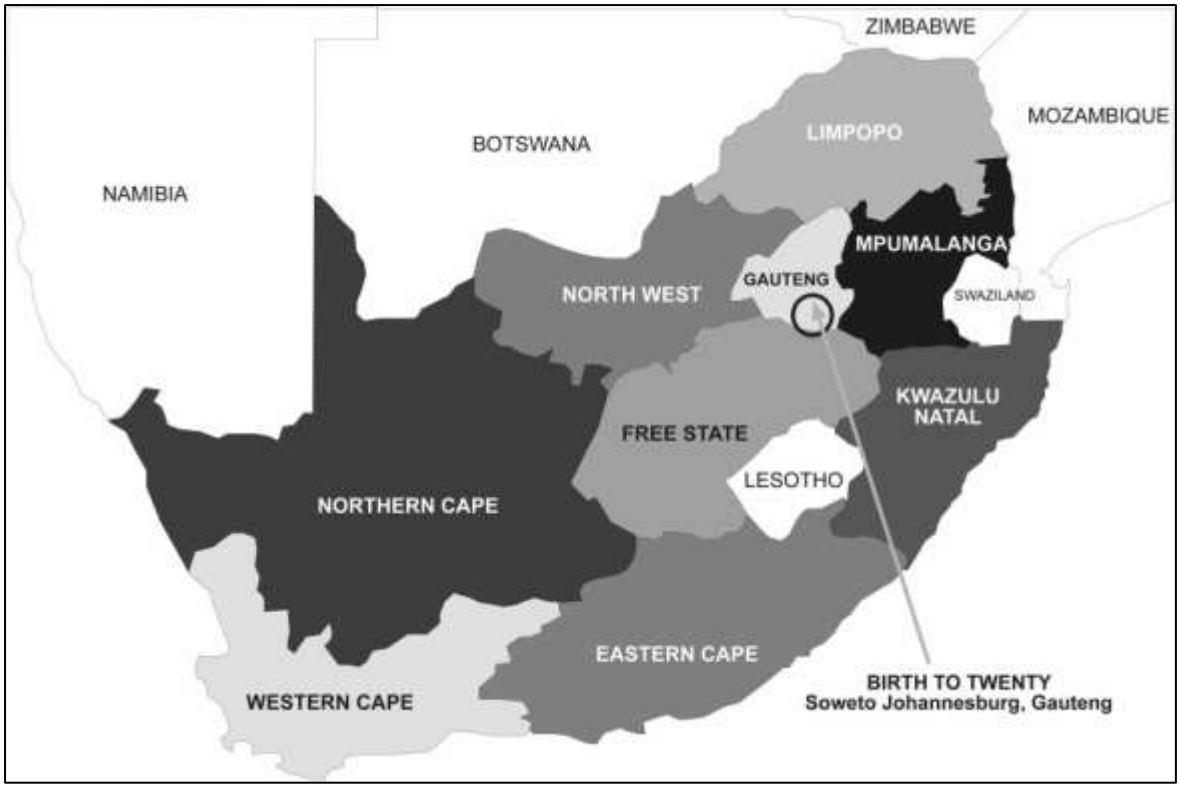


Figure 2.1: Map displaying Soweto, Johannesburg in the Gauteng province; source of data: Cohort Profile: Mandela's children: The 1990 birth to twenty study in South Africa (342)

2.3 Overview of the Birth–to–Twenty study cohort

The Birth–to–Twenty (Bt20) cohort study started in 1990 with a sample of 3,273 participants to examine the health and development of children born in the Soweto, Johannesburg region (Figure 2.1) (343). Women were enrolled in their second and third trimester of pregnancy through public health facilities and interviewed regarding their health and social history and current circumstances. Attrition over two decades has been comparatively low (30 %), mostly occurring during the children's infancy and early childhood (344). The Bt20 sample is representative of families that have remained residents of Soweto for over 20 years, with equal numbers of male and female participants. Bt20 also monitors the health of the biological mothers or caregivers of the children and it is from these subjects that the study cohort was drawn. A total of 2 200 caregivers/mothers remain in contact with the administrators of the study, resulting in the Bt20 study being the leading longitudinal study of

African health and development on the continent (344). The Bt20 data collection facilities are located at Bt20, Baragwanath Hospital, Soweto, and at the University of the Witwatersrand Medical School, Johannesburg. The Human Research Ethics Committee at the University of the Witwatersrand (Medical) granted ethical clearance to perform this study (M110627 – see Appendix 1). Participants gave consent to participate in the study (see Appendix 3)

Methods used in all of the publications

2.4 Height, weight, waist and hip circumference measurements

Total body weight (kg) was measured to the nearest 0.1 kg using a digital weighing scale (Dismedinc., Anjou, Canada) and standing height was measured to the nearest mm using a wall stadiometer (Holtain Ltd., Crosswell, UK). The participants wore minimal clothing and did not have shoes on during the measurements. Trained research assistants conducted the measurements, and the coefficients of variation for body weight and standing height measurements were both <1 %. Body mass index (BMI, $kg.m^{-2}$) was calculated and classified as normal-weight ($\geq$18.5 and < 25 $kg.m^{-2}$), overweight ($\geq$25 and < 30 $kg.m^{-2}$) or obese ($\geq$30 $kg.m^{-2}$) (48). Using a flexible, but inelastic measuring tape, a measurement of the waist circumference was taken at the narrowest part of the trunk, horizontally, while the participants were standing with arms at the side, relaxed abdomen, and feet together (48). Similarly, the hip circumference measurement was taken at the widest circumference of the proximal thigh, just under the fold of the gluteus, with feet separated slightly (48). The coefficients of variation (CV) were <1 % for body weight and standing height measurements, and <2 % for waist and hip circumference measurements (Appendix 4).

2.5 Dual–energy X–ray absorptiometry measurements

Dual–energy X–ray absorptiometry (DXA) (Hologic QDR 4500A, software version 11.2, Hologic Inc., Bedford, Massachusetts, USA) was used to measure total body fat mass, central

(trunk) and peripheral (arms and legs) adiposity, and total body, central (trunk) and peripheral (appendicular) fat–free soft–tissue mass. Anatomical sites were used as markers in DXA to determine cut-off lines for central and peripheral fat (345). The region for central fat mass included the area between the iliac crest and anterior surface of the mandible, with the spine, upper arm and truncal regions at the glenoid fossa, excluded by means of vertical (for spine) and lateral (for the latter region) boundary lines (346). The legs were separated by the central vertical line at the region where the oblique lines meet (from the underside of the foot to the iliac crest cut-off, along the femur and lower leg) (346). The glenoid fossa to the hand formed the anatomical markers for the arm. Coefficient of variances for DXA parameters were <2 % for total fat mass, and 1 % for fat–free soft tissue mass.

The arms included the region below the line through the glenoid fossa.

Vertical lines extending downward from the waist cut-off were positioned to separate thigh from hands, and oblique lines were positioned to pass through the femoral neck and join the central vertical line between the legs, in order to isolate the legs

2.6 Methods specific to the respective publications

Further detail specific to the publications can be found in the individual results chapters.

2.7 Statistical Analysis

The statistical methodology is described in the methodology sections of the individual results chapters.

PART 2

CHAPTER 3: PATTERNS, LEVELS AND CORRELATES OF SELF–REPORTED PHYSICAL ACTIVITY IN URBAN BLACK SOWETO WOMEN

3.1 Background

South Africa is a middle income country experiencing epidemiological transition due to rapid urbanisation. Nearly two thirds of the population live in urban areas, with the urban poor carrying the greatest risk of mortality from modifiable NCDs (27, 28, 347). Physical inactivity is accepted as one of the key chronic disease risk factors with 2008 estimations showing that physical inactivity was responsible for approximately 9.0 % of deaths globally (205), however data on its prevalence within developing countries are sparse (21).

South Africa is estimated to be the third most physically inactive country in Africa, with more than half of the population being physically inactive (51.1 %) (205). Studies have shown that South African women are more inactive than men (21, 337), suggesting that they may be at a higher risk for chronic diseases resulting from physical inactivity (348). A study from the South African Comparative Risk Assessment Collaborating Group has shown that in adult South African women, an estimated 27.7 % of colon cancer, 22.7 % of ischaemic strokes, 20.1 % of type 2 diabetes mellitus, 30.5 % of ischaemic heart disease, and 16.5 % of female breast cancer are attributed to inactivity (41). Black South African women have the highest prevalence of obesity (26), which may partly be influenced by socioeconomic status (22), but may also be related to physical activity since it has been observed that black females in South Africa have significantly less total energy expenditure than white women (349). Urban–dwelling black South African females have recently been confirmed to be less physically active than rural women who usually accumulate higher levels of physical activity by participating in subsistence related activity and walking (32). Data from the Transition and Health during Urbanisation of South Africans (THUSA) study has shown that physical inactivity is associated with obesity outcomes in black South African women (28). Sitting time, a proxy measurement for sedentary behaviour, increases the risk for all–cause mortality independent of physical activity time (350). Only a few studies have reported the estimated prevalence of sedentary behaviour in black South African females (32, 220, 351). These studies showed that rural women were significantly more sedentary than rural men (220), and that urban women were significantly more sedentary than rural women (32).

We hypothesise that urban, black African females have a high prevalence of obesity and metabolic disease both of which are associated with physical inactivity. Therefore, the aim of this study was three–fold: (i) to describe patterns of physical activity in a middle–aged cohort of urban black South African women who have recently been shown to have a high prevalence of metabolic syndrome and related disorders (4); (ii) to examine the association between socio–economic status and physical activity patterns in this cohort; and (iii) to determine if physical activity is associated with anthropometry and metabolic variables.

3.2 Methods

The methods used in this chapter that are common to the other results chapters have been described in Chapter 2. These methods are: the measurement of height (n=977), weight (n=977), waist and hip circumferences (both n=964), DXA derived whole body fat and fat–free, soft–tissue mass (FFSTM) (both n=655). The methods specific to this chapter, and which are described below are: the measurement of lipid profiles (HDL (n=462), LDL (n=462), serum triglycerides (n=463), and total cholesterol (n=463)), fasting glucose (n=551) and insulin (n=352), insulin resistance using the homeostasis model assessment (HOMA) technique, blood pressure (n=925), physical activity and sitting time minutes per week, and socioeconomic status.

3.2.1 Study population

The study design was cross–sectional, retrospective (data drawn from 2002/3) and included black African women living in an urban setting, who had previously been shown to have a high prevalence of metabolic syndrome (4). Participants for this study were included if they answered the Global Physical Activity Questionnaire (GPAQ) and excluded if they were from other ethnic groups, or younger than 18 years of age. The final sample size was 977 individuals which represented 78 % of the black South African caregivers from the original population of Bt20 caregivers (n= 1,251), and of whom 71. 8 % were biological mothers of the Bt20 index children.

3.2.2 Blood pressure

The Omron M6 (version HEM–7001–E, Omron, Kyoto, Japan) was used to record brachial blood pressure (BP). Three measurements were taken after the participant had rested (≥5 minutes) in the seated position with the cuff around the right upper arm, supported at the level of the heart (48). The average of the last two BP measurements was recorded (Appendix 4).

3.2.3 Blood collection and biochemical analysis

Participants were asked to fast overnight (minimum of 8 hours). The fasting period was confirmed on arrival to the data collection facility. Fasting blood samples were collected and centrifuged to obtain plasma and serum samples. Aliquoted samples were placed into cryovials and stored at –80 °C until assayed. The ADVIA Centaur XP Immunoassay System (Siemens Diagnostics, Tarrytown, USA) was used to perform immunoassays for fasting insulin, and the coefficient of variation (CV) range for the fasting insulin immunoassay was 5.9 to 4.8 %, while the reference range was 0.5 to 300 $\mu U.L^{-1}$. Insulin resistance was calculated using the homeostasis model assessment (HOMA) method (352). The ADVIA 1800 Chemistry System (Siemens Diagnostics, Tarrytown, USA) was used to determine lipid profile (total cholesterol [assay range; CV: 0.26 to 17.5 $mmol.L^{-1}$; 0.30 %]; high–density lipoprotein cholesterol (HDL): [0.10 to 3.00 $mmol.L^{-1}$; 1.00 to 2.30 %]; and serum triglycerides: [0.00 to 6.22 $mmol.L^{-1}$; 0.50 to 1.60 %]) and indicators of diabetes mellitus (fasting glucose [assay range; CV: 0.20 to 38.9 $mmol.L^{-1}$; 0.40 to 0.50 %]. The Friedwald formula was used to calculate low–density lipoprotein cholesterol (LDL) (353).

3.2.4 Diagnosis of cardiometabolic disease risk factors

Cardiometabolic disease risk factors were defined as systolic BP ≥130 mmHg, diastolic BP ≥ 85 mm Hg, fasting blood glucose ≥5.6 $mmol.L^{-1}$ (type 2 diabetes), triglycerides (TG) ≥ 1.7 $mmol.L^{-1}$, high–density lipoprotein cholesterol (HDL) <1.3 $mmol.L^{-1}$, low–density

lipoprotein cholesterol (LDL) ≥ 3 mmol.L^{-1}, and total cholesterol (TC) ≥ 5 mmol.L^{-1} (16). Central obesity was defined as a waist circumference ≥ 80 cm (16). Metabolic syndrome was defined using the harmonised guidelines (16).

3.2.5 Questionnaires

3.2.5.1 Physical activity and sitting time questionnaire

The Global Physical Activity Questionnaire (GPAQ) was completed via interview to obtain self–reported physical activity. This instrument is useful for large studies of physical activity patterns, and has been validated for use in both developed and developing settings (208). It has been utilised in South Africa and throughout other African countries (213). Data collected using this instrument allow for global physical activity surveillance and comparison of regional data, especially in Africa where there is limited physical activity and sedentary behaviour data. The GPAQ is also reliable for use in the South African setting, with satisfactory Kappa statistics ranging from 0.66 (93.9 % agreement) to 0.78 (89.3 % agreement) across various domains of physical activity (208). Total moderate–vigorous physical activity (MVPA) in minutes per week (mins/wk) were calculated from the accumulative occupation, travel–related (walking for travel) and leisure time physical activity. Examples of moderate (for example, mopping the floor at home) and vigorous (for example, carrying a load on the head while walking uphill) intensity activities in these various domains were explained to each of the participants. Walking for travel was analysed individually as it was the most common form of physical activity noted in the study population. Minutes per week of work and leisure time physical activity were combined. The reason for combining the constructs of work and leisure time physical activity was to isolate walking for transport as a unique construct. We could therefore analyse 'walking' independent of the former two constructs. Thus, we had a proxy measure of moderate-vigorous physical activity (in the form of work-leisure physical activity) which could be compared with light physical activity (in the form of walking for transport). Sitting time (measured in mins/wk) was obtained and used as a proxy measure of sedentary behaviour.

The participants were also grouped according to the GPAQ criteria, into GPAQ active or GPAQ inactive categories (209). The hours of physical activity and metabolic–equivalent (MET) values per activity were multiplied together to give MET minutes per week in order to determine GPAQ activity categories. Moderate activity was allocated a MET value of four and vigorous physical activity a value of eight as outlined in the World Health Organisation guidelines (209). GPAQ active was defined as taking part in: moderate physical activity for a total of 150 minutes per week (≥5 days per week); or vigorous physical activity for 60 minutes per week (≥3 days per week); or 600 MET minutes per week (≥5 days moderate–vigorous physical activity (MVPA)) (209). Participants who did not meet these criteria were classified as inactive (Appendix 5).

3.2.5.2 Socio–economic status

Socio–economic status was determined using a standardised household SES questionnaire, previously validated for use in this study population (354). The questionnaire was based on the ownership of twelve household commodities: electricity, television, radio, motor vehicle, refrigerator, washing machine, telephone, video machine, microwave, electronic media network television channel decoder for subscription television, digital satellite television, and mobile phone. The twelve household commodities were ranked in order of value and an overall SES score was then calculated using the ranks. The overall SES score ranged from 0 to 78. Television and motor vehicle ownership were stratified and analysed separately from the other household possessions as they are recognised as stimulators of sedentary behaviour (235, 355) (Appendix 8).

3.3 Statistical methods

Statistica version 12 (StatSoft, Tulsa, OK, USA) was used to carry out the statistical analyses (356). Prevalence levels for metabolic syndrome were determined using the harmonised guidelines (16) whilst diabetes was defined using the American Diabetes Association criteria (fasting glucose: ≥7 $mmol.L^{-1}$). Multiple imputation was used in dealing with missing body composition (fat mass, and fat–free, soft–tissue mass) and metabolic outcome variables

(fasting blood glucose, fasting insulin, HOMA, HDL, LDL, triglycerides, and total cholesterol). Multiple imputation was used to deal with the problem of missing data. Due to having multiple outcomes and the strong correlation amongst the outcome themselves, we used multiple imputation with chained equations. Examination of the patterns in missing data, showed a good proportion of participants having missing information in some outcomes but observed information in other outcomes. Thus, the chained equations used the available information in the outcomes, the relationship between the outcomes, and the relationship with other covariates in the imputations. As a consequence, different numbers for the variables are shown. Due to the amount of missing information in some variables, we checked how well the multiple imputation estimated the relationships. A comparison of results (model parameter estimates) showed no difference between analysis done using observed data and analysis done after multiple imputation. However, some factors that were initially not significantly correlated with the outcome variables were found to be correlated after imputation

Dependent variables that were not normally distributed (systolic BP, fasting blood glucose, fasting insulin, HOMA, LDL, HDL, triglycerides) were log transformed to normality. Model assumptions of normality and constant variance were tested using Q–Q plots, and plots of residuals versus predicted values, respectively. Data are presented as mean ± SD if normally distributed; otherwise median [interquartile range (IQR)] is presented.

T–tests were used to compare body composition and metabolic outcomes between Global Physical Activity Questionnaire (GPAQ) active and inactive subjects, individuals who presented with the extremes of moderate–vigorous physical activity (MVPA) (above 90^{th} and below 10^{th} percentile) and physical activity between subjects who owned or did not own a motor vehicle or TV. A cluster variable was created using sitting time with total MVPA and then using ANOVA to compare metabolic and body composition measures between subjects in: highest tertiles for MVPA and sitting time (n = 129), lowest tertile for MVPA and sitting time (n = 111), highest tertile for MVPA and lowest tertile for sitting time (n = 77) and lowest tertile for MVPA and highest tertile for sitting time (n = 90). The cluster variable was created to determine if a combination of two extremes of behaviour that are known to modulate fat mass affects both adiposity and metabolic function. Differences between tertiles of walking for travel MVPA were explored using an ANOVA for body composition

measures and metabolic outcomes, and Tukeys test, which takes into account multiple comparisons, was used for the post–hoc analysis.

Multiple linear regression analyses were performed to determine if any of the physical activity variables were associated with the body composition and metabolic variables. The dependent variables were: total body fat mass, fat–free soft tissue mass, waist circumference, HOMA, fasting blood glucose, fasting insulin, total cholesterol, LDL, HDL and triglyceride, and systolic and diastolic blood pressures. The independent variables to include in the initial models were chosen based on scientific plausibility and for the models with anthropometric measures as the dependent variable these were: age, SES, fat mass (for the waist model only), sitting time, total MVPA, work MVPA, leisure MVPA and walking for travel. The multiple linear regression models that used metabolic measures as the dependent variables included the following independent variables: age, SES, total body fat mass, fat–free soft tissue mass, waist circumference, sitting time, total MVPA, work MVPA, leisure MVPA and walking for travel MVPA. Before performing multiple linear regression, simple univariate regressions were used to determine which of the independent variables listed above were associated with the various dependent variables and those with $p<0.05$ were included in the regression models and all such variables were kept in the final model. The final models were also checked for multicollinearity using the Variance Inflation factor (VIF), but no multicollinearity was noted (all VIFs< 3.0). The results of the regression models are reported as standardised β values to facilitate direct comparisons of the strengths of the associations. Significance was accepted at a level of $p< 0.05$.

3.4 Results

3.4.1 Subject characteristics, anthropometric measures and metabolic outcomes

The mean age of this cohort was 41.0 ± 7.84 years, with a high mean BMI (30.3 ± 6.73 $kg.m^{-2}$) and waist circumference (86.9 ± 13.2 cm) (Table 3.1). The percentage fat mass was also high (40.8 ± 7.38 %). Fasting blood glucose levels were slightly raised, whilst insulin and HOMA levels were normal, and HDL levels were low (0.99 (IQR 0.78–2.00)), as were total cholesterol, LDL and triglyceride levels. Blood pressure values were within normal limits.

Table 3.1: Subject characteristics, body composition and metabolic outcomes of middle aged black African women from the Birth to Twenty caregiver cohort

Characteristics	**n**	**Mean ± SD or Median (IQR)**
Age (years)	964	41.0 ± 7.84
Body mass index ($kg.m^{-2}$)	977	30.3 ± 6.73
Waist circumference (cm)	964	86.9 ± 13.2
Hip circumference (cm)	964	112 ± 13.6
Waist–to–hip ratio	964	0.78 ± 0.08
Fat mass (kg)	655	28.9 ± 10.7
Fat–free, soft–tissue mass (kg)	655	38.1 ± 5.96
Fat percentage (%)	655	40.8 ± 7.38
Fasting blood glucose ($mmol.L^{-1}$)	551	5.09 (4.59–5.80)
Fasting insulin ($mU.L^{-1}$)	352	6.74 (4.46–9.14)
Homeostasis model insulin resistance	330	1.48 (0.96–2.11)
High–density lipoprotein cholesterol ($mmol.L^{-1}$)	462	0.99 (0.78–2.04)
Low–density lipoprotein cholesterol ($mmol.L^{-1}$)	462	1.31 (0.88–1.77)
Triglycerides ($mmol.L^{-1}$)	463	0.95 (0.71–1.67)
Total cholesterol ($mmol.L^{-1}$)	463	3.44 ± 1.77
Systolic blood pressure (mm Hg)	925	112 (103–126)
Diastolic blood pressure (mm Hg)	925	76.4 ± 12.5

Data presented as mean ± SD or median (interquartile range (IQR))

3.4.2 Physical activity

Physical activity data was obtained for 977 participants, 67 % of whom were classified as physically active according to the Global Physical Activity Questionnaire (GPAQ) criteria. When using the WHO criteria, 75 % of the participants met the minimum recommended guidelines for attainment of 150 minutes of moderate activity or 75 minutes of vigorous weekly activity (209). Age was not significantly different between the physical activity groups. All domains of physical activity, except vigorous PA ($p = 0.64$), were significantly higher (all $p < 0.001$) in the GPAQ active group compared with the GPAQ inactive group (Fig. 3.1 A and B). The median sitting time for the whole group was 3 hours a day, and was not significantly different between the activity groups (GPAQ active: 3 (IQR: 2–5) vs. GPAQ inactive: 3 (IQR: 1.5–4 hours per day).

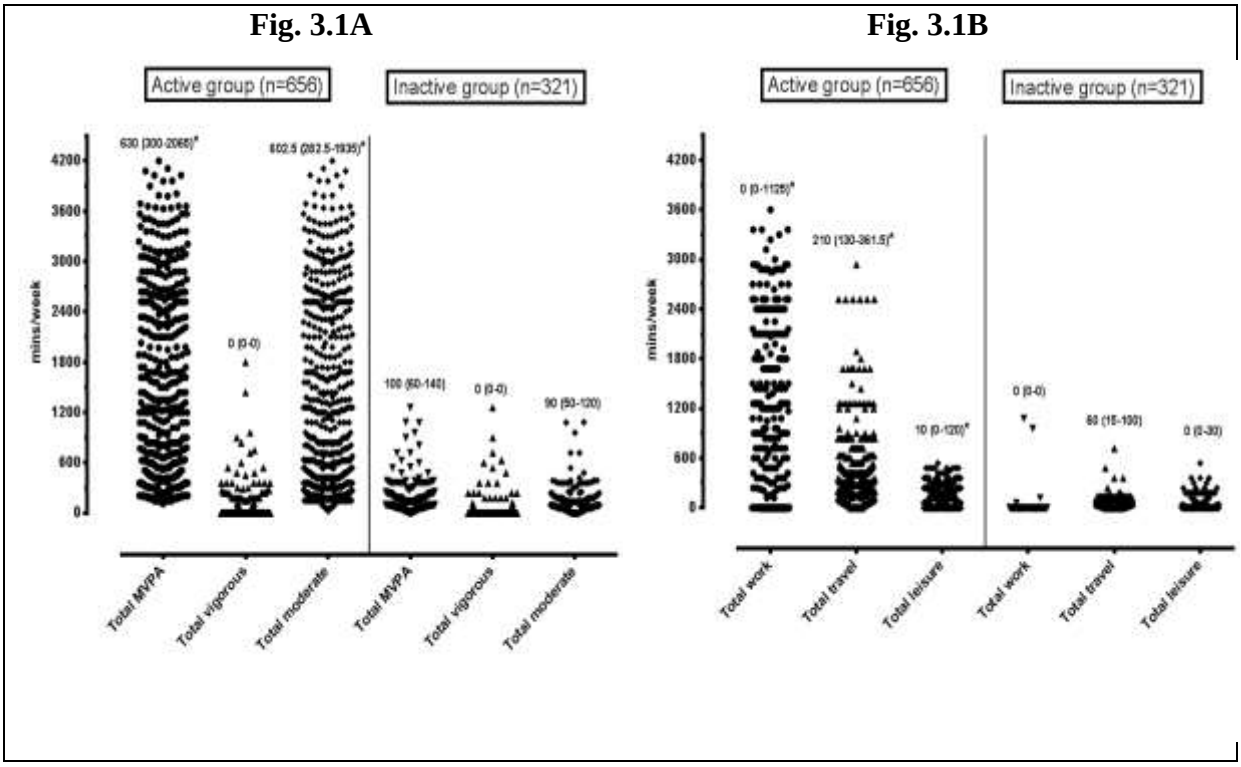


Figure 3.1: Comparative diagram of cumulative weekly physical activity for total MVPA, total vigorous and moderate physical activity (Fig. 3.1A), and physical activity in the occupation–, transport– and recreational–time (Fig. 3.1B) between GPAQ active and GPAQ inactive groups; $^{*}P < 0.05$ when compared with matching physical activity domain

3.4.3 Association between physical activity and socio–economic status (SES)

Household SES score was inversely associated with time spent walking for travel ($r = -0.10$; $p < 0.01$), but was not associated with any other activity variable. Walking for travel was divided into tertiles for analysis, lowest tertile: n = 322, 0–90 minutes per week; middle tertile: n = 316, 90–210 minutes per week; and highest tertile: n = 339, ≥ 210 minutes per week. Participants in the lowest tertile for walking for travel had a significantly higher household SES score (6.48 ± 2.29) compared with women in the middle (6.08 ± 2.28, $p < 0.05$) and highest (5.81 ± 2.37, $p < 0.001$) tertiles.

3.4.4 Sedentary promoting assets and physical activity

Time spent walking for travel was significantly higher in the women who did not own a motor vehicle compared with those who did ($p < 0.01$), and significantly higher in the women who did not own a television compared with those who did ($p = 0.001$) (Table 3.2). Leisure time physical activity was significantly higher in the women who owned a motor vehicle compared with those who did not ($p < 0.01$). Women who owned a television reported less MVPA minutes/wk ($p<0.01$) and total moderate PA ($p<0.01$), than women who did not own a television (Table 3.2). Sitting time in the GPAQ active group, 1260 (IQR: 840–2100) minutes per week, did not differ significantly from the inactive group, 1260 (IQR: 630–1680) minutes per week.

Table 3.2: Physical activity domains of participants who do and do not own a motor vehicle or television (TV) ownership

Physical activity domains*	**Motor vehicle and TV ownership**					
	No motor vehicle (n=601)	**Motor vehicle (n=211)**	**p–value**	**No TV (n=738)**	**TV (n=74)**	**p–value**
Total moderate–vigorous physical activity	400 (150–1320)	315 (150–1260)	0.53	615 (240–2160)	360 (150–1260)	0.004
Total moderate physical activity	360 (140–1260)	300 (120–1200)	0.46	615 (210–2100)	315 (120–1230)	0.002
Total vigorous physical activity	0 (0–0)	0 (0–0)	0.16	0 (0–0)	0 (0–0)	0.41
Total work (moderate–vigorous physical activity)	0 (0–330)	0 (0–0)	0.39	0 (0–720)	0 (0–0)	0.06
Total walking for travel	150 (60–300)	120 (40–240)	0.003	210 (120–420)	140 (60–280)	0.001
Total leisure (moderate–vigorous physical activity)	0 (0–120)	30 (0–120)	0.004	0 (0–180)	0 (0–120)	0.39
Work–leisure (moderate–vigorous physical activity)	60 (0–960)	90 (0–760)	0.38	120 (0–1680)	60 (0–60)	0.16
Sitting time	1260 (840–2100)	1260 (840–1680)	0.26	1260 (840–1680)	1260 (840–2100)	0.94

*Units are minutes/week expressed as median (interquartile range)

3.4.5 Association between physical activity, and anthropometric measures and metabolic outcomes

The prevalence of overweight was 29.2 % (95 % CIs 26.3, 32.0), obesity 48.0 % (95 % CIs 44.9, 51.1), 66.2 % of the women had a waist circumference ≥80 cm (95 % CIs 63.2, 69.1), diabetes was observed in 29.0 % (95 % CIs 25.2, 32.8) of the cohort and the prevalence of metabolic syndrome in this cohort was 40.0 % (95 % CIs 35.5, 44.6). Table 3.3 shows that the absolute levels of the anthropometric and metabolic variables did not differ between the GPAQ active and inactive groups. In addition, there were no significant differences between any of the anthropometric or metabolic variables when comparing women in the 90th (n=99) and 10th (n=101) percentiles for MVPA (data not shown). Sitting time was not different

between those with metabolic syndrome and those without (data not shown). The exploratory cluster variable also failed to show any significant differences between cluster groups for BMI, waist circumference, body fat, systolic blood pressure, diastolic blood pressure, fasting blood glucose, HDL, LDL, total cholesterol, and triglycerides (data not shown).

The results of the multiple regression analyses using observed data can be viewed in Appendix 11. Due to the amount of missing information in some variables, we checked how well the multiple imputation estimated the relationships. A comparison of results (model parameter estimates) showed no difference between analysis done using observed data and analysis done after multiple imputation. Using imputed data, multiple linear regression analysis demonstrated that sitting time was positively associated with HDL, triglycerides, and diastolic blood pressure (Table 3.4). The relationship between sitting time and HDL was confounded by the interaction between triglycerides and HDL. Thus, when triglycerides were added to the HDL model, sitting time showed an inverse, non–significant relationship with HDL (β coefficient: –2.13, p= 0.67). However, when triglycerides were removed from the HDL model, sitting time showed a positive association with HDL (β: 0.000002, p= 0.02). Inverse associations were observed between total MVPA and insulin, and between walking for travel and total cholesterol, whilst work MPVA was positively associated with fat–free, soft–tissue mass. Age was found to be positively associated with body fat, waist circumference, fasting blood glucose, total cholesterol, LDL, triglycerides, systolic and diastolic blood pressure, whilst SES was positively associated with body fat mass and fat–free, soft–tissue mass. Waist circumference was associated with fasting glucose, fasting insulin, LDL, total cholesterol, systolic and diastolic blood pressure (Table 3.4). No independent variables were found to correlate with HOMA levels following the regression analysis.

Table 3.3: Comparison of metabolic risk outcomes and body composition between active and inactive black South African women based on multiple imputation

Dependent variables	**GPAQ inactive**		**GPAQ active**	
	N	**Mean (95% CI)**	**N**	**Mean (95% CI)**
Fasting blood glucose ($mmol.L^{-1}$)	309	5.13 (4.92, 5.33)	630	5.32 (5.10, 5.53)
Fasting insulin ($pmol.L^{-1}$)	306	7.14 (6.31, 8.09)	625	6.78 (5.96, 7.71)
High–density lipoprotein cholesterol ($mmol.L^{-1}$)	306	1.27 (1.15, 1.40)	618	1.38 (1.23, 1.55)
Low–density lipoprotein cholesterol ($mmol.L^{-1}$)	306	1.26 (1.18, 1.35)	618	1.18 (1.12, 1.24)
Total cholesterol ($mmol.L^{-1}$)	306	3.52 (3.3, 3.75)	618	3.30 (3.10, 3.50)
Triglycerides ($mmol.L^{-1}$)	306	1.06 (0.98, 1.14)	618	1.10 (1.03,1.17)
Systolic blood pressure (mm Hg)	305	115 (112, 117)	620	114 (112, 117)
Diastolic blood pressure (mm Hg)	305	76.0 (74.0, 77.0)	620	77.0 (76.0, 78.0)
Fat mass (kg)	309	29.4 (28.2, 30.6)	635	29.0 (28.1, 29.9)
Fat–free, soft–tissue mass (kg)	309	38.1 (37.5, 38.8)	635	38.3 (37.8, 38.8)
Waist circumference (cm)	316	86.1 (84.6, 87.5)	650	87.2 (86.2, 88.3)
Body mass index ($kg.m^{-2}$)	321	30.2 (29.5, 31.0)	656	30.3 (29.8, 30.8)

Data expressed as mean (95% CIs); GPAQ: Global physical activity questionnaire

Table 3.4: Multiple linear regression models for anthropometric and metabolic variables using imputed data

Dependent variable	**N**	**Independent variables**	**Coefficients (95% CI)‡**	**Beta Coefficient† (p–value)**	**Adjusted R^2 (p–value)**
Fasting glucose	918	Age Waist	0.001 (0.0004, 0.002) 0.0007 (0.0003, 0.001)	0.10 (0.003) 0.11 (0.001)	0.02 (<0.001)
Fasting insulin	916	Age Waist Total MVPA	–0.002 (–0.005, 0.002) 0.006 (0.004, 0.007) –0.00002 (–0.00004, –0.000004)	–0.07 (0.04) 0.35 (<0.001) –0.11(<0.001)	0.13 (<0.001)
High–density lipoprotein cholesterol	914	Age Waist Sitting time	–0.001 (–0.003, 0.001) –0.003 (–0.004, –0.002) 0.00002 (0.000003, 0.00003)	–0.05 (0.16) –0.16 (<0.001) 0.08 (0.02)	0.04 (<0.001)
Low–density lipoprotein cholesterol	917	Age Waist	0.006 (0.002, 0.009) 0.002 (0.0005, 0.004)	0.28 (<0.001) 0.18 (<0.001)	0.13 (<0.001)
Total cholesterol	917	Age Waist Walking for travel	0.04 (0.02, 0.07) 0.009 (–0.009, 0.03) –0.0003 (–0.0009, 0.0002)	0.25 (<0.001) 0.09 (0.007) –0.08 (0.01)	0.09 (<0.001)
Triglycerides	921	Age Sitting time	0.002 (–0.0002, 0.004) 0.00002 (0.000001, 0.00004)	0.08 (0.01) 0.12 (<0.001)	0.02 (<0.001)
Systolic blood pressure	925	Age Waist	0.002 (0.002, 0.003) 0.0009 (0.0006, 0.001)	0.24 (<0.001) 0.17 (<0.001)	0.10 (<0.001)
Diastolic blood pressure	912	Age Waist Sitting time	0.21 (0.10, 0.30) 0.20 (0.14, 0.26) 0.001 (0.0002, 0.002)	0.13 (<0.001) 0.21 (<0.001) 0.08 (0.01)	0.08 (<0.001)
Body fat	925	Age SES score	201.03 (112, 291) 46.4 (9.82, 82.9)	0.15 (<0.001) 0.08 (0.009)	0.03 (<0.001)
Fat–free, soft–tissue mass	925	Age SES score Work MVPA	1.11 (–46.4, 48.6) 15.31 (–4.00, 34.62) 0.46 (–0.001, 0.92)	0.002 (0.96) 0.05 (0.12) 0.06 (0.05)	0.01 (0.098)
Waist circumference	925	Age	0.35 (0.25, 0.45)	0.21 (<0.001)	0.04 (<0.001)

‡: Unstandardised model coefficients; †: Standardised model coefficients; MVPA: moderate–vigorous physical activity

3.5 Discussion

The aim of this cross–sectional study was to determine the physical activity patterns of a cohort of middle–aged black women from Soweto, Johannesburg, who have previously been shown to be at high risk for metabolic disease. In this cohort of women in whom 67.0 % were classified as physically active, the prevalence of obesity was 48.0 %. This study is one of only a few to measure sedentary time in black South African women, and shows that despite a high level of physical activity and relatively low sitting time (214), metabolic disease risk is still high. Walking for travel significantly contributed to weekly physical activity, and was inversely associated with sedentary promoting assets including motor vehicle and television ownership.

The WHO defines being sufficiently active as accumulating a minimum of 150 minutes of moderate activity or 75 minutes of vigorous activity per week, however, this method does not take into account the various domains of physical activity (209). Physical activity in developed countries typically encompasses a greater contribution from leisure time activity, whereas in developing countries work– and travel–related physical activity are the major contributors to daily energy expenditure (211, 351). In addition, physical inactivity is higher in more affluent countries than lower income countries (210). However, longitudinal data from Brazil shows that physical activity has improved over a five year period in the lower socioeconomic stratum, suggesting a shift in physical activity patterns in low and middle income countries (203). Using the GPAQ criteria which also takes into account the number of days per week of PA, the majority (67.0 %) of women in this study were classified as physically active. This is comparable to the global level of physical activity in women (66.1 %), in a study which also highlighted the lack of physical activity data from low and middle income African and Asian countries (210). However, the physical activity range in our study falls into the higher end of the range reported in other studies of black South African women (45.2–70.8 %) (224, 238). In the study by Alberts *et al.* (2005) 45.2 % (age–standardized) of rural women were classified as physically active at home using a lifestyle questionnaire (238), while the THUSA study found that 70.8 % of rural women were physically active using a physical activity index which stratified the groups of physical activity in tertiles (224). In comparison to these two South African studies, most of the

women in the current study performed walking for travel (89.0 %) whereas the percentage of subjects commuting by walking was lower in the THUSA study (27.4 %) and the study by Alberts *et al.* (2005) (16 %). However, it should be noted that the methods used in these studies for assessing physical activity were different to those used in the current study, making comparisons difficult.

This is one of the first studies to quantify daily sitting time (excluding sleep time), a proxy for sedentary time (357), in a large female African population. Evidence from studies suggest that sitting time is associated with both obesity and other metabolic diseases (230, 231). In our study sitting time was positively associated with triglycerides and diastolic blood pressure, which has also been observed in other studies (230, 358). In the current study 50.0 % of the women reported sitting for 3 or more hours a day which is comparable to studies from India, China, and Brazil who report 3.5, 4, and 4.5 hours of sitting per day, respectively (232, 359). In our study, sitting time was not different between the active and inactive groups, suggesting that in this population, the amount of time spent sitting is independent of physical activity, and should be investigated as a distinct entity. This opinion is also shared by Bankoski *et al.* (226) and Chau *et al*. (360) who found that sedentary time was strongly related to the risk of metabolic disease independent of the time spent being physically active. Recent findings also show that patterns of sedentary behaviour varies by life domains such as television watching, personal computer use, and travel time (359).

Previous studies have identified motor vehicle ownership as a sedentary promoting asset (235, 236). Held et *al.* (2102) found that participants who owned a motor vehicle had an increased risk of myocardial infarction (236). Similarly the review by Douglas *et al.* (2011) emphasises the integral role of car ownership in the increasing prevalence of physical inactivity and obesity in countries with low levels of active transport (235). The current growth of the South African economy has resulted in motor vehicles becoming more affordable to a larger proportion of the population, as a result of which, vehicle ownership is increasing in urban settings such as Soweto (361). In our study, sitting time was not different between the women who owned motor vehicles and those that did not; however the women who did not own a motor vehicle walked significantly more and performed significantly less leisure time physical activity than the women who did own a motor vehicle. This data

suggests that the negative effect of car ownership on walking may be counteracted by an increased amount of leisure time physical activity. Leisure time physical activity has previously been shown to be associated with SES (212), so the role of SES and time spent in different sedentary life domains in determining physical activity patterns must also be considered (360).

The domains of physical activity in developing countries favour travel– and occupation–related physical activity, which was confirmed in our findings (211). Importantly, our study has provided data on the different domains of physical activity, which has only been investigated in a small number of African countries (213, 214, 351). Our findings show that the majority of the women (89.5 %) did not perform vigorous activity and that walking and occupational physical activities were the domains with the highest contribution (34 % from walking and 56 % from occupation related physical activity) to overall physical activity. A similar pattern of physical activity is evident in African countries such as Eritrea, Cameroon, Mali, and Mauritania, where active commuting contributes more than 50 % to total daily physical activity (213). Our study showed a positive association between activity in the work domain and fat–free, soft–tissue mass, suggesting that physical activity may have a role in improving the overall health profile of this ageing population of women, despite them having a high body fat percentage. It should be noted here that together with age and SES, this model only explained a small (1%) and non-significant % of the variance in fat–free, soft–tissue mass. A recent study however concurred with this finding, showing that exercise improved physical fitness and lean mass, but did not result in significant body fat or lipid profile changes following a 24 week intervention of strength and endurance training (362). Studies have also shown that participation in regular physical activity is the best means of preventing the effects of sarcopenia on the physical functioning of ageing individuals (141, 142). Leisure time activity contributes the most to overall physical activity in developed countries (21). A recent systematic review of the health benefits of walking as a means of transport confirms that there may be positive effects on hypertension and type 2 diabetes mellitus with longer duration walking (216).

A very high prevalence of type 2 diabetes was found in our study population with a mean age of only 41, and this is probably a result of the high level of obesity in this group. Our findings

showed that total MVPA was inversely associated with fasting insulin, indicating that being physically active has a role in enhancing insulin sensitivity. These results correspond with South African studies which showed that physically active urbanised black women had lower serum insulin levels than inactive women (28), subsequently resulting in higher levels of insulin sensitivity (214). These studies imply that meeting the recommended guidelines for physical activity may have long–lasting effects on insulin sensitivity.

This study used the GPAQ to measure physical activity. The GPAQ is cost–effective and has been validated for use in developing countries (211, 363). The reliability of the GPAQ has been tested in South Africa, with the results showed acceptable Kappa statistics, ranging from 0.66 (93.9 % agreement) to 0.78 (89.3 % agreement) across the domains of physical activity (208). However, the major challenge of using this instrument is that it assesses self–reported physical activity which may lead to an overestimation of weekly activity (364). Secondly, the GPAQ is not as sensitive as objective measurements of physical activity; however the GPAQ is still a useful tool for physical activity surveillance. Our South African data compares well with data from other African countries (213), such as Mozambique, Niger and Malawi who attain the majority of their activity from the work domain, ranging from 60 to 75% of total MVPA (213).

Another key drawback of this study is that it was cross sectional and therefore causality cannot be determined. We did not find an association between any of the physical activity domains and anthropometric measures or metabolic outcomes using a variety of statistical analyses. In an urban dwelling Cameroon population of women, lower amounts of MVPA was performed compared with ours (94 vs. 119 MVPA mins/per day) and a negative association was observed between physical activity and prevalence of metabolic syndrome (106). Cook et *al.* (2010) found that more than half of the women (55.2 %) in rural South Africa performed more than the recommended 10000 steps per day, and that ambulation reduced obesity risk in rural South Africans (220). A reasonable assumption for the differences between these studies and the current study could be in the use of self–reported questionnaires in our study compared with objective measurement of physical activity used in the other studies. However another reason for the difference could be that the prevalence of obesity was also lower in the Cook study (27.1 %) and similarly, the mean BMI of the

women in the Cameroon study ranged from 23.7 in the highest quartile of physical activity to 28.3 in the lowest. The employment status of this study population was not measured, thus we could not determine whether physical activity varied across occupation.

3.6 Conclusions

We have shown that despite the majority of urban dwelling black South African women being classified as physically active, there is still a high prevalence of obesity and metabolic disease in this population. As in other developing countries, the majority of time spent in physical activity is in the form of walking for travel, however the intensity of this activity is not known. Thus, we recommend that future research aims to determine whether the intensity of this walking modifies the level of cardiometabolic risk factors in this population. This study showed that sitting time was positively associated with serum triglyceride levels and diastolic blood pressure, whilst total MVPA was inversely associated with serum insulin levels. This data implies that future intervention studies for cardiometabolic disease prevention in urban African populations must aim to reduce daily sitting time and increase total MVPA.

CHAPTER 4: THE ROLE OF LIFESTYLE AND PSYCHO–SOCIAL FACTORS IN PREDICTING CHANGES IN BODY COMPOSITION IN BLACK SOUTH AFRICAN WOMEN

4.1 Background

Recent research has predicted that the proportion of overweight and obese women in developing countries such as South Africa will continue to rise, whereas the reverse applies to developed countries (2). The increasing prevalence of excess body fat deposition (observed in BMI values ≥25 $kg.m^{-2}$) in the South African population is associated with an excessive burden of several NCDs such as type 2 diabetes and hypertension (280, 365). Black South African women are more affected by obesity than men (23), a pattern that is common across the African continent and other developing countries (2). Furthermore, the recent South African National Health and Nutrition Examination Survey observed that a lower proportion of rural compared with urban black South African women have obesity (31.8% compared with 42.2 %) (23), as urbanised women live in an environment that favours unhealthy dietary patterns (30), reduced physical activity (PA) (21, 224), and greater sedentary time (32). However no studies have investigated whether these factors predict changes in body composition in an African population over time.

Psycho–social factors associated with obesity and body–size preference specific to black South African women have been reported in cross sectional studies (69, 70). These factors include social desirability to be fatter and a general tolerance of obesity (67). Black South African women and adolescent girls have been shown to underestimate actual body–size, indicating a high level of body–size discrepancy, and have a low level of body–size dissatisfaction (26, 68). Culturally a larger body–size is preferred as it is perceived to signify beauty, wealth, happiness, higher socioeconomic status, and ability to produce children (69), while thinness is associated with weakness, poverty and illness such as tuberculosis and human immunodeficiency virus (72). Furthermore, a recent study has shown that the body image silhouette chosen by urbanised black female adolescents for their ideal body silhouette represents a higher BMI than that chosen by white female adolescents. Within the same study, when asked what body silhouette they perceive their families would prefer them to have, black participants chose a silhouette with a BMI that was higher than that chosen by the white participants (77). This study also showed that a higher percentage of black girls had an EAT–26 (Eating Attitudes Test) score > 20 (indicating the possibility of developing eating disorders such as anorexia nervosa, bulimia nervosa, or preoccupation with food), and that a higher proportion of black adolescents girls, compared with white girls, had greater body–

size dissatisfaction, and were more likely to control what they ate. Another South African study similarly suggested that acculturation may be occurring in young black females, and that there could be a conflict between traditional beliefs and Western ideals around body–size (78). Most of the recent data relating to changes in perceptions about body size come from studies in adolescents, with little data available for middle-aged women. Therefore, the aim of this study was three–fold: (i) to describe the change in body composition over a 10 year period in a cohort of urban black South African women; (ii) to determine whether baseline measurements of body–size dissatisfaction and body–size discrepancy are associated with baseline body composition measures, and correlate with changes in body composition variables over 10–years of follow–up, and (iii) to determine whether baseline lifestyle factors including diet and physical activity are associated with changes in body composition.

4.2 Methods

The methods used in this chapter that are common to the other results chapters have been described in Chapter 2. These methods are: measurement of height, weight, waist and hip circumferences, DXA derived trunk fat, whole body fat and fat–free, soft–tissue mass (FFSTM). The methods specific to this chapter, and which are described below are: the measurement of body–size perception and body–size discrepancy, sitting time, physical activity, highest level of education, and asset ownership (proxy measure of socioeconomic status).

4.2.1 Study population

This longitudinal study included black SA urban–dwelling women from Soweto, Johannesburg. These women were caregivers of participants from the Birth to Twenty (Bt20) cohort, as described in Chapter 3. The majority (78.8%) of the sample were biological mothers of the Bt20 cohort, with the remainder being related to the child in some way. Baseline data were collected on all caregivers who were black African and > 18 years of age in 2002/3 (n=1,251). Follow–up data collection was completed 10 years later (2012/13) on 702 women, 428 of whom had anthropometric (weight and height) data at both time points.

4.2.2 Questionnaires

4.2.2.1 Physical activity and sitting time questionnaire

Baseline physical activity and sitting time were determined using the GPAQ (described in Section 3.2.5.1); however, participants were not stratified into physical activity groups for this study.

4.2.2.2 Socio–economic status

Ownership of household assets, a proxy measure of SES, was determined using a validated questionnaire (described in Section 3.2.5.2) (354). Level of education was also used as a proxy measure of SES for the longitudinal study, and was categorised as "no education" (coded as "0"), "completed primary school but did not attend high school" (coded as "1"), "attended high school but did not graduate" (coded as "2"), and "completed high school" (coded as "3") (Appendix 8).

4.2.2.3 Body–size dissatisfaction and body–size discrepancy

At baseline, drawings of nine female body silhouettes (adapted from Stunkard *et al.* (79)) ranging from "very thin" (numbered as 1) to "very heavy" (numbered as 9) were shown to participants and used to evaluate *body–size dissatisfaction* and *body–size discrepancy*. *Body–size discrepancy* was assessed by calculating a discrepancy score between perceived and actual weight status (PAD) using a method adapted from a South African (69) and an Italian (366) study. The participant chose a silhouette that they considered *best represented their current weight*. These were coded as follows: 1 = silhouettes 1 and 2 [underweight]; 2 = silhouettes 3 to 5 [normal weight]; 3 = silhouettes 6 and 7 [overweight]; 4 = silhouettes 8 and 9 [obese]). The PAD score was then calculated by subtracting the actual BMI status (coded using measured BMI as: 1 = underweight [<18.5 $kg.m^{-2}$], 2 = normal weight [18.5

to 24.9 kg.m^{-2}], 3 = overweight [25.0 to 29.9 kg.m^{-2}], 4 = obese [≥30.0 kg.m^{-2}]) from the code for the perceived weight status silhouettes. *Negative PAD scores represent underestimation* of weight status, *positive scores represent overestimation* of weight status, and *zero scores represent* participants who had an *accurate perception* of their weight status.

Body–size dissatisfaction was measured by asking the participant to choose the silhouette that best portrayed how they *wanted* to look (known as the 'ideal' body shape). This was then subtracted from the 'feel' score (the silhouette that portrays what they perceive themselves to look like) to calculate the feel minus ideal (FID) score. *Positive scores represent a desire to be leaner*, a *zero score represents contentment with body–size*, and *negative scores indicate a desire to be fatter* (69, 367). The body–size dissatisfaction and body–size discrepancy scores were used to categorise the participants into negative, zero and positive groups of PAD and FID (Appendix 6).

4.2.2.4 Dietary intake, alcohol consumption, and smoking status

High fat consumption was measured at baseline using an adapted food frequency questionnaire from a previous South African study investigating factors associated with overweight and obesity (368). The questionnaire determined consumption frequency of high–fat foods in the past week including fatty cuts of red meat, chicken with skin, full cream milk, processed meats, crisps, and fried food items, for example fried eggs, fish and French fries, consumed on a regular basis (≥1 day per week). Alcohol intake was categorised as low (1 drink per day), moderate (2–3 drinks per day), or high (>3 drinks per day). Smoking status (never smoked, current smoker, or former smoker) was also determined using this questionnaire. All participants were asked if they had attempted to lose weight in the last 24 months by reducing their food intake, taking diet shakes/drinks, and/or joining organisations which focus on structured weight reduction programmes (Appendix 7).

4.3 Statistical methods

Analyses were performed on the women for whom we had body composition and weight and height data at baseline and 10–year follow–up (N=428). The Statistica software package was used for all statistical analyses (version 12, StatSoft, Tulsa, USA) (356). Data that were not normally distributed (total MVPA, total walking for travel, vigorous physical activity, moderate physical activity, and total sitting time per week) were log transformed to normality. Continuous, normally distributed variables are presented as mean ± SD whilst data that was not normally distributed is presented as median (interquartile range [IQR]). Differences between baseline and 10 year data were assessed by Student's paired t–test or McNemer test. Variables were compared between the 3 FID, and between the 3 PAD groups, using ANOVA and followed by the Tukey *post hoc* test only in cases when the ANOVA was significant ($p< 0.05$). A cluster variable was created using physical activity and consumption of fatty foods with ANOVA used to compare body composition across the following groups: physically inactive and consume high fat foods (n = 100), physically inactive and consume low fat foods (n = 19), physically active and consume high fat foods (n = 240), physically active and consume low fat foods (n = 33). The cluster variable was created to determine if a combination of two extremes of behaviour that are known to modulate fat mass affects adiposity.

Multiple linear regression analyses were conducted to determine if baseline (predictor) variables were associated with absolute changes in the body composition (outcome) variables (FFSTM, waist circumference, BMI, central adiposity, peripheral adiposity, and total body fat mass) 10 years later after adjusting for potential confounding variables, i.e. age, SES score, education, and the respective baseline body composition variables. Results of the multiple linear regression models are presented as standardised β values to enable direct comparison of the strengths of the associations. Prior to performing multiple regression analysis, simple bivariate analyses were performed to determine which of the following baseline (predictor) measures [total vigorous physical activity, total walking for travel, alcohol use, cluster variable for physical activity status and consumption of fatty foods, smoking status, weight loss practices, FID score and PAD score] were associated with the various dependent variables, and those with $p< 0.05$ were included in the multivariate regression models along

with the four possible confounding variables described above. Only the independent variables that had significant ($p< 0.05$) β values are reported in the results section. Collinearity between independent variables was assessed using the Variance Inflation Factor (VIF), and no collinearity was observed (all VIFs< 2.0). Dummy variables were generated for the following variables: FID and PAD scores, the cluster variable for physical activity and consumption of fatty foods, education, smoking status, and alcohol consumption. The reference groups for each of these variables were as follows: zero FID, zero PAD, physically active and low fat consumption, no education, non–smokers, and people who do not consume alcohol. Significance was accepted at an alpha level of $p\leq 0.05$.

4.4 Results

4.4.1 Characteristics of the study cohort

Mean age at baseline was 41.1 ± 5.35 years and at follow–up age was 49.3 ± 5.33 years. Within the study cohort 49.5 % of participants had completed high school. Complete DXA data was not available at both time points for all subjects due to the fact that not all study subjects were able to perform DXA scans at the baseline visit on weekdays due to work commitments and we could only accommodate a small number of subjects for data collection on weekends. Women for whom DXA data was available at both time points (n=264) were slightly older, but showed no differences for any of the other measured variables when compared with women without (n=164) DXA data (Appendix 13). There was a significant increase in all body composition measures between baseline and follow up (all $p<0.001$), with a mean weight gain for the whole sample of 5.17 ± 8.86 kg (Table 4.1). The prevalence of a high waist circumference (≥80 cm) and obesity (BMI≥30 $kg.m^{-2}$) increased significantly between baseline and follow–up (both $p < 0.001$).

Table 4.1: Body composition characteristics at baseline and at 10–year follow–up

Variable	**N[a]**	**Baseline**	**Follow–up**	**Percentage change**
Weight (kg)	428	77.4 ± 17.3	82.6 ± 18.9[*]	7.13 ± 12.1
Body mass index (kg.m^{-2})	428	30.8 ± 6.70	33.1 ± 7.36[*]	7.98 ± 11.9
Waist circumference (cm)	415	87.7 ± 13.2	98.5 ± 14.7[*]	12.8 ± 11.4
Hip circumference (cm)	413	114 ± 13.7	119 ± 15.2[*]	4.09 ± 7.44
Waist–to–hip ratio	413	0.77 ± 0.08	0.83 ± 0.08[*]	8.65 ± 9.96
Fat mass (kg)	264	29.8 ± 10.2	32.9 ± 10.6[*]	13.6 ± 23.75
Fat–free, soft–tissue mass (kg)	264	38.5 ± 5.86	45.0 ± 7.29[*]	17.2 ± 7.99
Central adiposity (kg)	261	13.4 ± 5.28	14.4 ± 5.33[*]	11.6 ± 28.7
Peripheral adiposity (kg)	261	16.4 ± 5.49	17.7 ± 5.84[*]	9.8 ± 20.5
Obesity (BMI≥30 kg.m^{-2})	428	50.9 (46.2, 55.7)	65.8 (61.4, 70.4)[*]	29.3[†]
Waist (≥80 cm)	415	70.6 (66.2, 75.0)	89.9 (87.0, 92.8)[*]	27.3[†]

Data presented as mean ± SD for continuous data and % (95 % CIs) for categorical data; [a]N at baseline and at 10–year follow–up; [*]$p < 0.001$ versus baseline values; [†]Formula for percent change in prevalence: (follow–up prevalence – baseline prevalence)/baseline prevalence

4.4.2 Body–size perception and body–size discrepancy

At baseline, 10.5 % of subjects wanted to be fatter (negative FID score), 57.4 % wanted to be leaner (positive FID score), and 32.1 % were content with their body image (zero FID score; Table 4.2). The proportion of women in each of these groups did not change significantly at follow–up, i.e. 9.1 % subjects wanted to be fatter, 53.7 % wanted to be leaner, and 37.2 % were content with their body–size. At baseline, women who wanted to be leaner had a significantly higher BMI, waist and hip circumferences, central and peripheral adiposity, and total fat and fat–free, soft–tissue mass, than those with a negative or zero FID score ($p<0.0005$ for all comparisons). Similar differences were observed at follow up (Appendix 14 and 14). There were no differences between the FID groups for absolute change in any of the body composition measures even when this data was expressed as percentage change from the baseline, and when FID negative and zero groups were combined and compared with the FID positive group.

Table 4.2: Comparison across baseline FID groups of baseline body composition measures and absolute change in body composition variables over 10–year follow–up

Variable	**Subjects who wanted to be fatter**	**Subjects who were content with their body**–size	**Subjects who wanted to be leaner**
Proportion in each FID group (%)[b]	10.5% (45)	32.1% (138)	57.4% (247)
Proportion of obesity in each FID group (mean % (95% CIs))[b]	13.6 (3.08-24.2)	36.5 (28.3-44.7)	65.6 (59.6-71.6)
Age (years)	42.2 ± 5.84 (45)	42.1 ± 5.49 (138)	40.3 ± 5.05 (247)
BMI ($kg.m^{-2}$)[b]	25.1 ± 4.16 (44)	28.4 ± 4.91 (137)[†]	33.2 ± 6.85 (247)[††† ***]
Absolute change in BMI ($kg.m^{-2}$)	1.46 ± 2.99 (44)	2.60 ± 3.54 (137)	2.31 ± 3.54 (247)
Waist circumference (cm)[b]	77.2 ± 8.21 (45)	83.4 ± 10.4 (136)	91.8 ± 13.6 (243)[††† ***]
Absolute change in waist circumference (cm)	10.5 ± 8.11 (43)	11.1 ± 8.91 (134)	10.7 ± 10.0 (238)
Hip circumference (cm)[b]	102 ± 9.28 (45)	110 ± 10.8 (136)[†]	119 ± 13.8 (242)[††† ***]
Absolute change in hip circumference (cm)	2.98 ± 6.08 (43)	4.58 ± 7.42 (133)	4.69 ± 9.86 (237)
Fat mass (kg)[b]	20.2 ± 6.35 (33)	28.0 ± 9.29 (87)[†]	33.4 ± 10.4 (157)[††† *]
Absolute change in fat mass (kg)	4.02 ± 6.04 (32)	3.53 ± 6.10 (84)	2.72 ± 5.89 (148)
Fat–free, soft–tissue mass (kg)[b]	35.9 ± 5.10 (33)	37.1 ± 5.18 (87)	40.3 ± 6.38 (157)[††† ***]
Absolute change fat–free, soft–tissue mass (kg)	5.78 ± 2.99 (32)	6.49 ± 2.88 (84)	6.80 ± 3.26 (148)
Central adiposity (kg)[b]	8.68 ± 3.34 (32)	12.3 ± 4.68 (86)	15.2 ± 5.29 (155)[††† *]
Absolute change in central adiposity (kg)	1.56 ± 2.88 (30)	1.15 ± 3.20 (84)	0.79 ± 3.10 (147)
Peripheral adiposity (kg)[b]	11.5 ± 3.56 (32)	15.6 ± 5.05 (86)	18.1 ± 5.82 (156)[††† *]
Absolute change in peripheral adiposity (kg)	1.64 ± 2.67 (30)	1.48 ± 3.06 (84)	1.29 ± 3.46 (148)

Data presented as mean ± SD (n); $^{\dagger}P< 0.05$, $^{\dagger\dagger\dagger}P< 0.0005$ versus subjects who wanted to be fatter; $^{*}P< 0.05$, $^{***}P< 0.0005$ versus subjects who were content with body shape; ^{b} baseline values

With regard to body–size discrepancy at baseline, 74.0 % of the subjects underestimated their actual body–size (negative PAD score), 2.00 % overestimated actual body weight (positive PAD score), and 24.0 % correctly perceived their actual body weight (zero PAD score; Table 4.3). At follow up, the proportion of women in each of the PAD groups were similar to baseline, i.e. 73.5 %, 0.70 %, and 25.8 % respectively. Women who underestimated actual body weight status had a significantly higher BMI, waist and hip circumferences, and total fat and fat–free, soft–tissue mass, than those who overestimated or correctly perceived their actual body weight ($p<0.0005$ for all comparisons). Women who correctly perceived actual body weight had a significantly greater increase in fat mass than the women who underestimated body weight.

There were 316 participants who underestimated their body–size. These subjects had a high BMI (32.6 ± 5.74; see Table 4.3) and 60.1 % of them wished to be leaner i.e. had a positive FID score, 8.20% wanted to be fatter, and 31.7 % were content with their body–size. The women who underestimated but were content with their body–size were older (42.7 ± 5.28 vs 40.4 ± 5.16 years; $p< 0.05$) and less obese (30.3 ± 4.01 vs 34.5 ± 5.78; $p< 0.0005$) than those women who wanted to be thinner, and less of them completed high school compared with the latter group (46.0% vs 56.3%; $p= 0.06$). There were 103 participants who accurately perceived their body–size, of whom 17.5% wanted to be fatter, 35 % were content with their body–size and 47.5 % wanted to be leaner (for the latter value (47.5 %), $p< 0.05$ vs those subjects who underestimated body–size and wanted to be lean (60.1 %)).

Table 4.3: Comparison across baseline PAD groups of baseline body composition measures and absolute change in body composition variables over 10–year follow–up

Variable	**Subjects who underestimated actual body–size**	**Subjects who accurately perceived actual body–size**	**Subjects who overestimated actual body–size**
Proportion in each PAD group (%)[b]	74.0% (316)	24.0% (103)	2.00% (9)
Proportion of obesity in each PAD group (mean % (95% CIs))[b]	65.8 (60.5-71.1)	9.70 (3.89-15.5)	0 (0-0)
Age (years)	41.3 ± 5.41 (316)	40.3 ± 5.18 (103)	42.4 ± 4.64 (9)
BMI ($kg.m^{-2}$)[b]	32.6 ± 5.74 (316)	26.2 ± 6.89 (103)	21.5 ± 2.39 (9)[†††] [***]
Absolute change in BMI ($kg.m^{-2}$)	2.17 ± 3.60 (316)	2.80 ± 3.66 (103)	1.81 ± 2.47 (9)
Waist circumference (cm)[b]	91.0 ± 11.9 (312)	78.6 ± 12.3 (101)	72.0 ± 6.93 (9)[†††] [*]
Absolute change in waist circumference (cm)	10.4 ± 9.73 (307)	12.3 ± 8.79 (97)	10.6 ± 6.97 (9)
Hip circumference (cm)[b]	117 ± 12.2 (312)	106 ± 13.8 (100)	94.4 ± 7.81 (9)[†††] [***]
Absolute change in hip circumference (cm)	4.17 ± 9.14 (306)	5.54 ± 7.88 (96)	4.73 ± 5.98 (9)
Fat mass (kg)[b]	33.3 ± 9.38 (209)	21.2 ± 7.98 (60)	15.2 ± 5.03 (7)[†††] [***]
Absolute change in fat mass (kg)	2.57 ± 6.92 (198)	5.04 ± 5.99 (59)[†††]	3.24 ± 3.88 (6)
Fat–free, soft–tissue mass (kg)[b]	40.3 ± 5.66 (209)	34.8 ± 4.99 (60)	28.4 ± 2.59 (7)[†††] [***]
Absolute change in fat–free, soft–tissue mass (kg)	6.89 ± 3.13 (198)	5.88 ± 2.87 (59)	3.86 ± 2.44 (6)
Central adiposity (kg)[b]	15.6 ± 4.67 (206)	8.79 ± 4.02 (59)	6.33 ± 2.35 (7)[†††] [***]
Absolute change in central adiposity (kg)	0.73 ± 3.10 (196)	1.85 ± 3.11 (58)	1.20 ± 2.28 (6)[†††]
Peripheral adiposity (kg)[b]	18.1 ± 5.26 (206)	12.3 ± 4.60 (60)	8.86 ± 3.21 (7)
Absolute change in peripheral adiposity (kg)	0.99 ± 2.98 (196)[*]	2.74 ± 3.93 (59)	1.25 ± 1.71 (6)

Data presented as mean ± SD (n); $^{\dagger}P< 0.05$, $^{\dagger\dagger\dagger}P< 0.0005$ versus subjects who underestimated actual body–size; $^{*}P< 0.05$, $^{***}P< 0.0005$ versus subjects who accurately perceived actual body–size; [b]baseline values

4.4.3 Lifestyle factors

The median (IQR) sitting time for all participants at baseline was 1260 (840–1890) minutes per week, and was significantly different ($p< 0.05$) between the subjects who wanted to be fatter (1680 (840–2940) minutes per week) compared with the subjects who were content with their body–size (1260 (840–1680) minutes per week) and the subjects who expressed a desire to be thinner (1260 (840–1680) minutes per week). For all participants the median time spent in walking for travel was 150 (60–300) minutes per week, for work MVPA was 0 (0–0) minutes per week, and for leisure MVPA was 0 (0–120) minutes per week. Total median MVPA was 350 (150–1240) minutes per week, total vigorous physical activity and total moderate physical activity were 0 (0–0) and 315 (150–1240) minutes per week, respectively. None of these physical activity variables measured at baseline were associated with body–size discrepancy or body–size dissatisfaction, and were also not significantly different between the PAD or FID groups.

The majority of participants (88.2 %) reported consuming butter or margarine on bread, 55.9 % reported eating chicken with skin, 48.6 % ate processed meat, 33.7 % ate red fatty meats, and 49.8% drank full cream milk on a regular basis (>1 time per week). A significantly higher amount of women who wanted to be leaner consumed fatty red meat compared with those women who wanted to be fatter (44.4 % vs. 13.5 %, $p<0.05$). The majority (97.0 %) of the participants did not smoke, and 16.7 % consumed alcohol on a regular basis (≥1 time per day), whilst 25.7 % had participated in some form of weight loss strategy in the past 24 months. A significantly higher number of women who wanted to be leaner participated in some form of weight programme compared with those women who indicated a desire to be fatter (84.0 % vs. 13.0 %, $p<0.0001$). No significant differences were noted between the groups defined using the cluster variable (physical activity and fatty food intake) for changes

in body composition (as determined by ANOVA). This cluster variable also did not contribute significantly to the multiple regression models shown in Table 4.4.

Table 4.4: Multiple linear regression analyses displaying the major predictors of change in body composition in black African women from Soweto

Model number	**Dependent variables**	**N**	**Independent variables**	**Significant beta coefficients (P–value)**	**R^2 (P-value)**
1	Absolute change in waist circumference	380	Alcohol intake at baseline (>3 drinks/day)	–0.15 (0.003)	0.07 (<0.0001)
			Total vigorous PA (baseline)	–0.15 (0.002)	
			Waist circumference (baseline)	–0.17 (0.001)	
			Active smoker at baseline	-0.02 (0.66)	
			Subjects who wanted to be fatter (baseline)	-0.05 (0.37)	
			Subjects who wanted to be leaner (baseline)	0.06 (0.35)	
			Subjects who underestimated actual body–size (baseline)	-0.001 (0.99)	
			Subjects who overestimated actual body–size (baseline)	-0.03 (0.38)	
			Attended high school but did not graduate	0.06 (0.45)	
			Completed high school	0.02 (0.98)	
2	Absolute change in body mass index	430	Total vigorous PA (baseline)	–0.11 (0.02)	0.02 (<0.01)
3	Absolute change in fat–free, soft–tissue mass	241	Active smoker at baseline	–0.14 (0.02)	0.12 (<0.0001)
			Age (baseline)	–0.14 (0.03)	
			Fat–free, soft–tissue mass (baseline)	0.21 (0.003)	
4	Absolute change in total body fat	264	Subjects who underestimated actual body–size (baseline)	–0.16 (0.01)	0.08 (<0.0001)
			Total body fat (baseline)	–0.22 (0.002)	
			Total vigorous PA (baseline)	–0.12 (0.04)	
5	Absolute change in central adiposity	260	Central adiposity (baseline)	–0.24 (0.001)	0.09 (<0.0001)
			Total vigorous PA (baseline)	–0.15 (0.01)	
6	Absolute change in peripheral adiposity	261	Subjects who underestimated actual body–size (baseline)	–0.15 (0.03)	0.06 (<0.001)
			Total vigorous PA (baseline)	–0.13 (0.04)	

Data presented as standardised beta coefficient (p–value)

4.4.4 Multivariate regression

The multivariate regression models showing the contribution of various baseline factors to change in body composition are presented in Table 4.4, with age, SES, education and the respective baseline body composition variables included in each of the 6 models. Total vigorous physical activity and high alcohol consumption (≥3 drinks/day) were each inversely associated with absolute change in waist circumference (model 1). In the model for absolute change in BMI (model 2), total vigorous physical activity was the only significant independent variable. Smoking and age were inversely associated with change in FFSTM, while baseline FFSTM was positively associated (model 3). Although the prevalence of smoking was low (3 %) an effect was seen on change in FFSTM and this is due to a strong effect of smoking as shown by the difference in change in FFSTM between smokers (n=13) and non–smokers (n=382) (3.03 ± 2.81 vs 6.69 ± 3.13, p= 0.003). Model 4 showed that total vigorous physical activity and baseline total body fat were both inversely associated with an absolute change in total body fat, which was lower in those who underestimated body–size when compared with those who accurately assessed body–size. Total vigorous physical activity and baseline central adiposity were both inversely associated with change in central adiposity (model 5). Total vigorous physical activity and an underestimation of body–size were both negatively associated with absolute change in peripheral adiposity (model 6).

4.5 Discussion

In this cohort of ageing black South African women we observed significant weight gain over a 10 year period, with an obesity prevalence of 65.8 % at follow up, and with nearly 90 % of the participants having a waist circumference ≥80cm. The most significant contributors to less change in the various body composition measures were the underestimation of body–size at baseline, time spent doing vigorous physical activity, and alcohol consumption.

This study is the first to determine the contribution of body image to long–term body composition change in black South African women. Our study demonstrates that the majority (57.4 %) of the women wished to be leaner, and that these women had higher baseline BMI,

total body fat and fat–free mass, central and peripheral adiposity, waist and hip circumference values, than the women who wanted to be fatter and those who were happy with their body–size. In contrast, previous cross–sectional studies have shown that African women have a general acceptance of overweight and obesity (67), with a larger body–size traditionally being viewed as a symbol of beauty, wealth, happiness, and optimal fertility in African cultures (67, 69, 71), whereas leanness was associated with sickness and lower socioeconomic status (72). Our data therefore suggests that within our cohort of adults the acceptance of female obesity within African traditions exists side–by–side with a more western ideal of a lower body weight. Within adolescent black females the situation is similar, with the study of Gitau *et al.* (77) showing that although black adolescent females are more comfortable with a body–size that is higher than that selected by white adolescents females, the black females were more likely to have a predisposition toward eating disorders than their white counterparts. This again suggests a clash between the traditional African view of overweight/obesity as being the ideal female body state and the modern Western tradition of leanness as the ideal female body state (78).

This is the first study to have measured whether the discrepancy between actual and perceived weight status in South African women predicts future weight gain. The majority (74%) of women at baseline underestimated their weight and had significantly higher measures of all body composition parameters at baseline, when compared with the other groups. However these women had less absolute change in central and peripheral adiposity at follow up when compared with those subjects who had accurately estimated their body–size. This may be related to the fact that a higher proportion of this group wanted to be leaner when compared with the subjects who accurately identified their body–size. This may be advantageous for future obesity intervention programs. Other South African studies have also shown that black African females tend to underestimate their actual body–size (26, 68). However, 31.7 % of the women who underestimated their body–size were content with their weight status, even though their mean BMI was high at 30.3 ± 4.01. Fewer of these women had completed high school and were older than those women who wished to be leaner. These data suggest that within our study population there are two distinct groups of overweight/obese women who differ in terms of age, education and the desire to lose weight. These findings may be important when introducing obesity intervention programs into this population, with different approaches required for each group of women.

This is the first longitudinal study on the effect of physical activity on weight change in black African females. Our results showed that baseline total vigorous physical activity was inversely associated with change in BMI, waist circumference, total body fat, and central and peripheral adiposity. These results are comparable to those from a study conducted in middle–aged obese and sedentary American women which showed that higher intensity physical activity was more effective in reducing both intra–abdominal and subcutaneous fat than lower intensity physical activity (369). Further, it has been observed that exchanging 1 hour of sitting time with light physical activity can significantly decrease both visceral and subcutaneous adipose tissue (370). In our study, sitting time was significantly lower in those women who wanted to be leaner compared with those women who wanted to be fatter, but body–size dissatisfaction and body–size discrepancy were not associated with differences in the level of physical activity. This data suggests that body–size dissatisfaction or discrepancy may not have an impact on physical activity behaviour in this population, which is contrary to one previous study which has shown that physical activity is perceived to be associated with thinness (68), and that body–size dissatisfaction may modulate sedentary behaviour. Moreover, participating in vigorous physical activity provides additional advantages to health such as improved skeletal health and reduced risk of cardiovascular diseases (371). However, only 10% of the women in our study participated in vigorous intensity physical activity, which is similar to the data for women from other developing countries (21, 213). These data suggest that efforts to combat obesity in this population should include higher intensity physical activity programmes, however the programmes should emphasise the gradual and safe progression from light to higher intensity, particularly in those women who are obese.

Findings in other studies of alcohol consumption and body weight have shown that more frequent drinking is associated with leanness (372, 373), while binge drinking is associated with central obesity (321). In comparison, our findings show that higher alcohol consumption was inversely associated with change in waist circumference. This finding is consistent with a large Danish longitudinal study which showed that the level of alcohol intake was inversely associated with change in waist circumference in women (374). The authors attribute this result to a thermogenic effect, i.e. the action of alcohol dehydrogenase and the microsomal ethanol–oxidising system increasing thermogenesis in frequent alcohol

drinkers. Our analysis also shows that smoking has an inverse association with change in FFSTM, implying that women in our cohort who smoke gain less muscle mass over time. Our findings also show that age was negatively associated with change in FFSTM, reinforcing the well documented loss of muscle mass with ageing (375). The main result of premature sarcopenia would be a loss of functional capacity, particularly for activities of daily life that require muscle strength. Nicotine acts as an appetite suppressant and increases energy expenditure, which may explain the reason for smokers tending to have lower body weight than non–smokers, and why smoking cessation is followed by an increase in fat mass (297). As active smoking was only observed in 3 % of the cohort in our study, and because tobacco consumption was only captured at baseline is causality should be inferred with caution. With regards to dietary behaviour, we showed that many of the women in our study ate foods high in fat. In spite of this, the consumption of these foods did not influence long term weight gain. This is consistent with a large American study, which showed a weak non–significant correlation between weight change and whole fat dairy foods, but a strong negative correlation with nuts, vegetables and fruits (376).

In South Africa (26, 76, 272) and other sub–Saharan African countries (273, 274), SES has been shown to be positively associated with obesity in cross sectional studies, as has level of education (26, 76, 272-274). However, the findings from our study show that baseline measures of education or SES did not affect change in body composition. The reason for this finding is not known however one possible explanation may be the low variation in education and SES levels within this cohort. Socioeconomic status and alcohol intake were only measured at baseline in our study and therefore the effect of changes in these variables could not be assessed. However it is unlikely that SES would change sufficiently over the study period to modulate any of the outcome variables. It is possible that alterations in alcohol consumption over the 10 year period may have effects on body composition changes, but it must be noted that the prevalence of alcohol usage in this cohort was low.

This longitudinal study has a number of limitations including the use of self–reported physical activity and sedentary behaviour, derived from the GPAQ instrument. This questionnaire has the potential to overestimate both physical activity and sitting time. However, GPAQ has been shown to be reliable for use in African populations (208), and our

findings are comparable with physical activity data from other African countries (213), and adds to a small body of evidence from low–and–middle–income countries. Secondly, the self–reported dietary questionnaire only considered high fat foods which have previously been associated with obesity in South Africa (368). We observed that consumption of these foods were common amongst the participants in this study. Future studies in this population should also consider the impact of other foods which were not considered in the present investigation e.g. high carbohydrate foods and sugar sweetened drinks. Thirdly, it would have been ideal to have more regular follow–up visits of this cohort, but due to infrastructural constraints this was not possible. The 10–year period allowed for greater changes of the anthropometric variables than would be observed over a shorter time period thus allowing us to more easily isolate predictor variables. It is nevertheless important to emphasise that it is not known if the changes in body composition over the 10–year period are linear, as assumed in the multivariable linear regression analyses. A further limitation was that DXA data was not available for the full cohort. However, when comparing the women for who complete DXA data was available to those for who it was not, there were no differences in any of the measured variables with the exception of age, which was slightly lower in the latter group. This suggests minimal selection bias for the group with DXA data available at both time points. Lastly, an assumption has been made that the desire for, or the acceptance of, a higher body–size is the consequence of a traditional African belief in the positive aspects of obesity. Questions were not asked of the study participants to validate this assumption, although previous reports have described such beliefs (67, 69). Comparison with a European population would have allowed us to determine whether this acceptance of a high body–size was more prevalent in an African population, although other studies have shown this to be the case (70, 77).

4.6 Conclusions

The findings of this longitudinal study demonstrate that in our cohort of black urbanised South African women time spent in vigorous physical activity was associated with smaller increases in body weight and adiposity. However, only a small percentage of subjects participated in vigorous PA. In addition, the majority of participants who were overweight or obese underestimated their body–size and this was related to a smaller gain in body adiposity and a more prevalent desire to lose weight than in subjects who accurately identified their

body–size. Additionally, in agreement with previous studies that have reported that black South African women are more accepting of being obese (67, 69, 71), our study highlighted the existence of a further group of overweight/obese women who were content with their body–size. Thus, the presence of two distinct groups of overweight/obese women within our study population, one wishing to be thinner (57.4%) and the other content with their body–size (32.1%), may reflect a clash of traditions with the former group appearing to be more closely aligned with Western values focussing on leanness and the latter group more aligned with the African ideal of overweight/obesity as the preferred body–size. It is recommended that more in–depth studies of these groups are necessary to determine whether these assumptions are correct and to investigate whether obesity intervention programs would require different approaches in each of these populations.

CHAPTER 5: METABOLIC AND BODY COMPOSITION RISK FACTORS ASSOCIATED WITH METABOLIC SYNDROME IN A COHORT OF WOMEN WITH A HIGH PREVALENCE OF CARDIOMETABOLIC DISEASES

5.1 Background

Metabolic syndrome, which is one of the major pandemics affecting health across the globe (86), is characterised by a clustering of cardiometabolic factors which increase the risk of cardiovascular disease and type 2 diabetes (16). A complete understanding of the aetiology of the metabolic syndrome is difficult to achieve due to the presence of multiple components, each of which have their own individual pathophysiological origins. Furthermore, the metabolic syndrome includes metabolic (lipids and glucose), cardiovascular (blood pressure) and visceral adiposity (waist circumference) factors with the latter of these, itself having an aetiological input into each of the other components (377). Thus, when investigating the aetiology of the syndrome, risk factors may be revealed simply because of their correlation with waist circumference.

A number of risk factors for metabolic syndrome have been demonstrated (20) however; there is little data on how disease risk varies across the range of levels of these variables or whether individual factors modulate the disease risk contributed by other identified risk markers. Such information would be important to our understanding of the aetiology of the metabolic syndrome and may improve our ability to identify true markers of disease risk. The identification of risk factors for metabolic syndrome and a greater understanding of their inter-relationships may be accomplished by the investigation of populations with high levels of cardiometabolic disease prevalence. This is true for urban South African females in whom the prevalence of both obesity and metabolic syndrome are high [11] and little is known about the disease aetiology.

Therefore, the aims of the current study were as follows to: (i) identify the main contributing factors to the cardiometabolic features of the metabolic syndrome in a cohort of urban African women known to have a high prevalence of metabolic syndrome; to determine how disease risk varied across the range of levels of each risk factor; and (ii) examine whether each risk factor modulated the contribution of the other factors to disease risk across their range and to determine which individual components of the metabolic syndrome were influenced by each of the risk factors. We hypothesised that each risk factor would modify

the contribution of the other factors to disease risk by varying degrees across their range. We further hypothesised that each of these factors will influence metabolic syndrome risk by effects on individual components of the syndrome. It was hoped that this investigation would identify the principal risk factors for metabolic syndrome and reveal novel information on the interplay between these factors in modulating disease risk.

5.2 Methods

The methods used in this chapter that are common to all the other results chapters have been described in Chapter 2. These methods are: measurement of height, weight, waist and hip circumferences, DXA derived trunk fat, whole body fat and fat–free, soft–tissue mass (FFSTM). Measurement of lipid levels, insulin, insulin resistance and glucose were also undertaken in this chapter and are described in detail in Chapter 3 (see section 3.2.3), whilst measurement of blood pressure is also described in Chapter 3, section 3.2.2. Methods specific to this chapter are described below and are: measurement of adiponectin, leptin, HbA_{1c}, HIV status, visceral and subcutaneous abdominal fat, employment status, education level, menopausal stage, smoking and use of smokeless tobacco (snuff).

5.2.1 Study population

This cross–sectional study of African women comprised 867 eligible women for recruitment into the current study based on the following criteria: age between 40–60 years, not being pregnant and being black South African. However, 165 of this group could not participate in the study, for the following reasons: refusal (n = 79), uncontactable (n = 46), died (n = 37), and terminally ill (n = 3). Thus 702 women volunteered to participate, and underwent an informed consent process. Ethical clearance was granted by the Human Research Ethics Committee (Medical), University of the Witwatersrand.

5.2.2 Body composition

5.2.2.1 Ultrasound analysis

The GE LOGIQ ultrasound system (USS) (GE Healthcare, Piscataway, NJ) was used to determine the thickness of visceral (VAT) and subcutaneous adipose tissue (SCAT) with a 2 to 5 MHz 3C–RS curved array transducer located one centimetre above the umbilicus. The ultrasonographic measurements were defined as the distances (depth set at fifteen centimetres) from the peritoneum to vertebrae (for VAT), and the depth (distance set at nine centimetres) from the surface of the skin to the linea alba (for SCAT). A trained sonographer administered all the measurements (CV <2 %, calculated on repeated duplicate measurements on fifteen subjects). The methods used for SCAT and VAT measurement by ultrasonography have been previously validated (378).

5.2.3 Blood pressure

The method used for the measurement of blood pressure has been described in Section 3.2.2.

5.2.4 Blood collection and biochemical analysis

In addition to the protocol used for the collection of fasting blood and biochemical analysis, the methods used to determine HbA1c, adiponectin, and leptin concentration are outlined. The ADVIA 1800 Chemistry System (Siemens Diagnostics, Tarrytown, USA) was used to measure glycated haemoglobin (HbA1c) [CV, 0.8 to 1.3 %]). The low–density lipoprotein cholesterol (LDL) was estimated using the Friedewald formula (379). Leptin was measured using an ELISA kit (Biovendor Research and Diagnostic Products, Candler, NC) with a CV range of 4.2 to 7.6 %. Total adiponectin was quantified using an ELISA assay kit (R&D Systems Inc., Boston Biochem, Cambridge, MA) with a CV range of 2.5 to 4.7 %.

5.2.5 Diagnosis of disease and assessment of menopausal status

The cut–points used for diagnosis of each of the individual components of the metabolic syndrome were those from the harmonized guidelines (16). Metabolic syndrome was diagnosed using 2 different methods: (1) waist circumference was excluded from the assessment and the syndrome was diagnosed when 3 or more of the remaining 4 criteria were met; (2) waist circumference was included and diagnosis was based on the presence of 3 or more of the 5 criteria as prescribed by the harmonized guidelines (16).

A trained HIV counsellor performed HIV testing and recorded the HIV status of the participants. The Alere Determine ^{TM} HIV–1/2 (Alere Medical Co., San Diego, CA) assay kit for the rapid detection of HIV antigens/antibodies was offered to all study participants. It is considered to have a high level of acceptance, sensitivity and specificity in African populations (380). Referral to the nearest public hospital or community clinic of was made to validate HIV positive findings with more in–depth analyses to ensure appropriate treatment. Management of HIV using antiretroviral pharmacotherapy was also noted.

Menopausal status (pre– or post–menopause) was determined by a trained clinician using the STRAW +10 criteria (381).

5.2.6 Questionnaires

5.2.6.1 Socio–economic status

Education (completed high school or did not complete high school) and employment status (employed or unemployed) were determined (see questionnaire in Appendix 8).

5.2.6.2 Tobacco and smokeless tobacco consumption

Cigarette smoking ("never" as reference versus "current" and "former") and smokeless tobacco (snuff) status ("yes" or "no") were determined from questions taken from a standardised, validated general health questionnaire (368) (Appendix 7).

5.3 Statistical analysis

All analyses were performed using Statistica (version 12, StatSoft, Tulsa, USA). Continuous, normally distributed variables are presented in tables and text as mean ± SD whilst continuous variables with a skewed distribution are shown as median (interquartile range). The latter variables were log transformed to normality before being analysed. Metabolic and anthropometric differences were compared between women with and without metabolic syndrome using either a Student's unpaired t–test for continuous data or a χ^2 test for categorical data.

Logistic regression analysis was carried out to identify if any of a list of scientifically plausible variables were associated with metabolic syndrome. Each of these variables were included in a separate univariate logistic regression model with metabolic syndrome as the outcome variable. These variables were: education (completed or did not complete high school), age, employment status (employed or unemployed), snuff use ("yes" or "no"), smoking ("never" as reference versus "current" and "former"), menopausal status (pre- or postmenopausal), HIV status (HIV–negative as reference versus HIV-positive, antiretroviral therapy (ART)–naïve and HIV–positive, receiving ART), adiponectin, leptin, HOMA, subcutaneous and visceral adipose thickness, total body fat, total FFSTM, hip and waist circumferences. The variables that were associated with metabolic syndrome risk in the univariate logistic regression models with $p<0.10$ (see section 5.4.2 for a list of these variables) were all included in a single multivariable logistic regression model with metabolic syndrome again as the outcome variable. Backward, stepwise removal of non–significant variables was performed manually until only variables with a significant odds ratio (OR) remained in the final model. Collinearity within both the initial and the final model was

quantified via variance inflation factor (VIF) analysis, but none was observed with all VIFs < 5.00. Each of the independent continuous variables that remained in the multivariable logistic regression model were then analysed as hexiles, with the lowest hexile used as the reference, in the presence and absence of each of the other independent variables that significantly associated with metabolic syndrome. This allowed us to determine how risk for metabolic syndrome varied across the range of each independent variable and whether this was affected by the other significant modifiers of metabolic syndrome risk. In addition, the risk factors for each component of the metabolic syndrome (except waist) were determined using multivariable, backward step–wise logistic regression analysis as described above.

A *post hoc* power analysis was performed based on the multivariable logistic regression models and using the model that would require the largest sample size. This model had 10 independent variables (k) and the frequency of the categorical variable was 0.142 (p). Using the equation, N=(10k)/p this model required a sample size of 704 subjects, which was very close to the actual N for this study (702).

5.4 Results

5.4.1 Subject characteristics

Body composition and metabolic features of the participants with or without metabolic syndrome are presented in Table 5.1. Metabolic syndrome was diagnosed using only HDL, triglyceride, glucose and blood pressure measurements, and 3 or more of these 4 measurements had to exceed the cut points defined by the harmonised guidelines (16). The prevalence of metabolic syndrome using these criteria was 14.0 % whilst the prevalence using the normal criteria that includes waist circumference (16), was 49.6 %. The prevalence of the individual components of the metabolic syndrome were as follows: waist circumference ≥80 cm, 90.5 %; hypertension, 64.7 %; fasting glucose ≥5.6 mmol.L^{-1}, 16.3 %; triglyceride ≥1.7 mmol.L^{-1}, 15.4 %; HDL <1.3 mmol.L^{-1}, 66.2 %. The prevalence of obesity was 67.8 %, of extreme obesity (BMI ≥ 40) was 16.8 %, of LDL ≥3 mmol.L^{-1} was 36.4 % and of total cholesterol ≥5 mmol.L^{-1} was 29.9 %. The data in Table 5.1 demonstrates that nearly all the anthropometric and cardiometabolic variables were higher in the women with metabolic syndrome than those without, whereas socioeconomic and education status were similar between the two groups. When comparing the data in Table 5.1 with data from

women diagnosed with or without metabolic syndrome using the full set of 5 criteria from the harmonised guidelines (16) (see Appendix 16), it was observed that in these women both leg fat (14.8 ± 4.31 vs. 13.5 ± 4.72 kg; $p<0.0005$) and leptin (31.1 [18.6, 45.9] vs. 22.7 [13.1, 40.5]; $p<0.0005$) were significantly higher in subjects with metabolic syndrome but no such differences were observed for the women depicted in Table 5.1. In addition, subcutaneous fat thickness was not different ($p=0.083$) between women with (3.49 ± 1.01 cm) or without (3.35 ± 1.03 cm) the metabolic syndrome when diagnosed using the full criteria, but when using the criteria without waist, subcutaneous fat thickness was lower in women with metabolic syndrome ($p<0.05$; see Table 5.1).

Table 5.1: Anthropometric and metabolic variables in women with and without metabolic syndrome[†]

Variables	**Women with metabolic syndrome[†] (n=90)**	**Women without metabolic syndrome (n=552)**
Proportion (mean (95%CIs))	14.0 (11.3-16.7)	86.0 (83.3-88.7)
Age (years)	51.0 ± 5.21	49.0 ± 5.19**
Weight (kg)	86.0 ± 14.2	79.1 ± 16.0**
Height (m)	1.58 ± 0.07	1.57 ± 0.06
BMI ($kg.m^{-2}$)	35.4 ± 6.75	32.8 ± 7.26*
Waist (cm)	106 ± 11.2	97.5 ± 14.4***
Hip (cm)	121 ± 13.3	117 ± 14.8*
Arm fat (kg)	4.13 ± 1.08	3.63 ± 1.26**
Arm FFSTM (kg)	4.86 ± 0.89	4.36 ± 0.80***
Leg fat (kg)	14.0 ± 4.22	14.1 ± 4.64
Leg FFSTM (kg)	16.5 ± 2.81	15.4 ± 2.82**
Trunk fat (kg)	16.5 ± 4.15	14.0 ± 5.13***
Trunk FFSTM (kg)	23.7 ± 3.26	21.4 ± 3.18***
Total body fat (kg)	34.6 ± 8.47	31.8 ± 10.2*
Total FFSTM (kg)	45.0 ± 6.57	41.2 ± 6.55***
Subcutaneous fat thickness (cm)	3.21 ± 0.74	3.45 ± 1.06*
Visceral fat thickness (cm)	5.07 ± 1.56	4.29 ± 1.72***
Systolic blood pressure (mmHg)	143 [130, 159]	128 [117, 143]***
Diastolic blood pressure (mmHg)	93.0 [87.5, 101]	86.0 [77.5, 94.5]***
HbA1c (%)	6.30 [5.90, 7.70]	5.80 [5.50, 6.20]***
Fasting glucose ($mmol.L^{-1}$)	5.70 [5.00, 7.20]	4.70 [4.40, 5.10]***
Insulin ($pmol.L^{-1}$)	13.5 [8.60, 20.0]	9.80 [6.40, 14.1]***
HOMA	3.93 [2.22, 5.69]	2.01 [1.31, 3.10]***
Adiponectin ($\mu g.mL^{-1}$)	4.54 [3.33, 6.77]	7.52 [4.94, 11.2]***
Leptin ($ng.mL^{-1}$)	28.0 [18.7, 45.3]	27.3 [14.8, 43.6]
Total cholesterol ($mmol.L^{-1}$)	4.48 ± 1.12	4.49 ± 1.05
LDL ($mmol.L^{-1}$)	2.66 ± 0.99	2.73 ± 0.88
HDL ($mmol.L^{-1}$)	1.00 [0.90, 1.10]	1.20 [1.00, 1.50]***
Triglycerides ($mmol.L^{-1}$)	1.80 [1.20, 2.10]	1.00 [0.80, 1.30]***
Employed (%)	53.3 (42.8, 63.8)	57.5 (53.4, 61.7)
Completed high school (%)	33.3 (23.2, 43.4)	29.6 (25.7, 33.4)
Smokers (%)	13.3 (6.17, 20.5)	7.43 (5.23, 9.62)
Consume snuff (%)	13.5 (6.25, 20.7)	21.8 (18.4, 25.3)

[†]Metabolic syndrome diagnosis was made in subjects in whom 3 or more of the following 4 variables exceeded the cut points set out by the harmonised guidelines (16): blood pressure, glucose, triglyceride and HDL levels; data expressed as mean ± SD, median [interquartile range] or % (95% CIs); BMI = body mass index; HOMA= homeostasis model assessment; *$p<0.05$, **$p<0.005$, ***$p<0.0005$ vs women with metabolic syndrome

5.4.2 Univariate and multivariate logistic regression analyses of metabolic syndrome risk

In separate, unadjusted, logistic regression models the following variables were associated with metabolic syndrome (diagnosed using only HDL, triglyceride, glucose and blood pressure measurements) risk at $p<0.10$: HOMA, adiponectin, waist and hip circumference, total body fat mass, total body FFSTM, subcutaneous and visceral fat thickness, age, menopausal status, receiving ART and smoking. These variables were then included in the same multivariable logistic regression model with metabolic syndrome as the outcome variable. Following backward, stepwise removal of variables with no significant ($p>0.05$) association with metabolic syndrome, the following variables remained in the final model: HOMA, adiponectin, total body FFSTM, subcutaneous fat thickness, age and smoking. Total body FFSTM is a composite variable of leg, arm and trunk FFSTM and therefore these variables were included in the initial multivariate logistic regression model (without total body FFSTM) and the backward stepwise removal of non-significant variables was repeated resulting in the final logistic regression model shown in Table 5.2. It can be seen that trunk FFSTM remained in the model alongside the same variables described above i.e. HOMA, adiponectin, subcutaneous fat thickness, age and smoking. Leg and arm FFSTM did not remain in this model. When a multivariable logistic regression model was built for metabolic syndrome diagnosed using the full criteria, the final model contained HOMA, adiponectin, age and trunk FFSTM but not subcutaneous fat thickness or smoking (see Table 5.2).

The attenuation of metabolic syndrome risk by subcutaneous fat (see model 1 in Table 5.2) was further investigated by performing a univariate linear regression analysis of the relationship between subcutaneous fat and insulin resistance (HOMA, acting as dependent variable). This gave a significant, positive relationship (unstandardised $\beta=0.04$, $p=0.003$) that was severely attenuated ($\beta=0.003$, $p=0.79$) when waist circumference ($\beta=0.009$, $p<0.0005$) was included as an additional independent variable.

Table 5.2 Logistic regression models showing significant risk factors for metabolic syndrome diagnosed using criteria with or without inclusion of waist circumference

Model number	Categorical variable	Independent variables	Odds ratio (95 % CI's); p-value
1	Presence of metabolic syndrome (criteria without waist)	Trunk FFSTM:	1.34 (1.10, 1.61); 0.002
		Subcutaneous fat:	0.56 (0.39, 0.79); 0.001
		Adiponectin:	0.84 (0.77, 0.92); <0.0005
		HOMA:	1.31 (1.16, 1.48); <0.0005
		Age:	1.10 (1.04, 1.16); 0.001
		Smoking:	3.07 (1.28, 7.33); 0.01
2	Presence of metabolic syndrome (criteria with waist)	Trunk FFSTM:	1.19 (1.11, 1.27); <0.0005
		Adiponectin:	0.94 (0.91, 0.98); 0.004
		HOMA:	1.31 (1.16, 1.47); <0.0005
		Age:	1.08 (1.04, 1.12); <0.0005

HOMA: homeostasis model assessment; FFSTM: fat–free, soft–tissue mass

5.4.3 Risk factors for each of the individual components of the metabolic syndrome

Table 5.3 displays backward, stepwise multivariable logistic regression models for each of the 4 cardiometabolic components of the metabolic syndrome. Visceral fat, HOMA, age, and smoking are associated with an increased risk of high serum triglyceride levels, whilst adiponectin and leg fat are associated with reduced risk (model 1). In model 2, snuff use and adiponectin are associated with a reduced risk of low HDL levels, whereas trunk FFSTM is associated with a higher risk. Model 3 shows that adiponectin and subcutaneous fat reduce the risk of impaired fasting glucose, whereas age and HOMA increase the risk. It should be noted that in univariate analyses HOMA correlated very strongly with insulin (r=0.95) when compared to glucose (r=0.40) suggesting that HOMA is a much stronger marker of insulin than glucose levels. Age and waist circumference are each associated with an increased risk of hypertension (model 4).

Table 5.3: Logistic regression model showing significant risk factors for the components of the metabolic syndrome

Model number	Categorical variable	Independent variables	Odds ratio (95% CI's); p-value
1	***Triglyceride ≥ 1.70 mmol/L***	Visceral fat	1.22 (1.04, 1.44); 0.02
		Leg fat	0.85 (0.79, 0.92); <0.0005
		Adiponectin	0.92 (0.86, 0.98); 0.006
		HOMA	1.11 (1.00, 1.24); 0.05
		Age	1.07 (1.02, 1.12); 0.007
		Smoking	2.53 (1.21, 5.30); 0.01
2	***HDL < 1.30 mmol/L***	Trunk FFSTM	1.14 (1.04, 1.24): 0.005
		Adiponectin	0.93 (0.90, 0.97); <0.0005
		Snuff use	0.63 (0.40, 0.99); 0.05
3	***Glucose ≥ 5.60 mmol/L***	Subcutaneous fat	0.59 (0.42, 0.83); 0.002
		Adiponectin	0.93 (0.87, 1.00); 0.04
		HOMA	1.73 (1.49, 2.00); <0.0005
		Age	1.09 (1.03, 1.15); 0.002
4	***Blood pressure ≥ 130/85 mmHg***	Waist	1.05 (1.01, 1.08); 0.005
		Age	1.05 (1.00, 1.11); 0.04

HOMA: homeostasis model assessment; FFSTM: fat–free, soft–tissue mass

5.4.4 Risk for metabolic syndrome across hexiles of each risk factor

Figure 5.1 shows the odds ratios (ORs) for metabolic syndrome risk across hexiles (quintiles for trunk FFSTM) of each of the continuous independent variables found in the final multivariable logistic regression model shown in Table 5.2. The ORs are shown both unadjusted and adjusted for all the other independent variables in the final model (Table 5.2). Trunk FFSTM was analysed as quintiles because with hexiles only 1 metabolic syndrome case was observed in the first hexile. The unadjusted ORs for metabolic syndrome risk are significant for each trunk FFSTM quintile, rising to a maximum in quintile 5 (see Fig 5.1A).

However, after adjustment for all the other variables, all ORs fell with only quintile 5 demonstrated a significant OR ($p<0.005$). This attenuation of risk was analysed in more detail by adding each of the variables to the model one at a time. It was observed that only the addition of adiponectin to the model caused any of the trunk FFSTM quintiles i.e. quintiles 3 and 4, to become non-significant, suggesting that adiponectin was largely responsible for the risk attenuation. Figure 5.1B shows a similar analysis of metabolic syndrome risk across hexiles of subcutaneous fat thickness. The unadjusted ORs for metabolic syndrome rise fom hexile 1 to a peak at hexile 3 and then fall progressively to a nadir at hexile 6. Only hexile 3 shows a statistically significant OR ($p<0.05$). After adjustment for all the variables, the ORs were all lower, with hexile 3 becoming non-significant but hexile 6 now showing a significantly lower ($p<0.05$) OR relative to hexile 1. Adding each of the variables on their own to the model or in combination demonstrated that the addition of trunk FFSTM with adiponectin produced a model that mimicked that observed when all variables were added together. The analysis of HOMA hexiles (Fig 5.1C) shows that for the unadjusted ORs, risk for metabolic syndrome increased from hexile 1 to reach a maximum at hexile 6, with hexiles 4 ($p<0.05$), 5 ($p<0.05$) and 6 ($p<0.0005$) all showing statistically significant ORs. Adjusting for all the variables reduced all the ORs, leaving only hexile 6 with a significant OR ($p<0.005$). Further analysis demonstrated that adiponectin in combination with trunk FFSTM were the main contributors to this effect. The data in Fig 5.1D shows that for adiponectin hexiles, the unadjusted ORs for metabolic syndrome drop from hexile 1 to 2, plateau till hexile 4 and then drop to hexile 5 with a nadir at hexile 6. All ORs are significantly different to that for hexile 1. After adjustment for all variables the ORs increase slightly but only the OR for hexile 4 becomes non-significant ($p=0.054$). When age is divided into hexiles, the unadjusted ORs for metabolic syndrome rise steadily from hexile 1 to hexile 6, with significant ($p<0.05$) ORs observed at hexiles 5 and 6 (Fig 5.1E). A very similar pattern is observed for the fully adjusted ORs, which show no attenuation. With regards smoking, the OR for metabolic syndrome remained significant with or without adjustment for all the other variables.

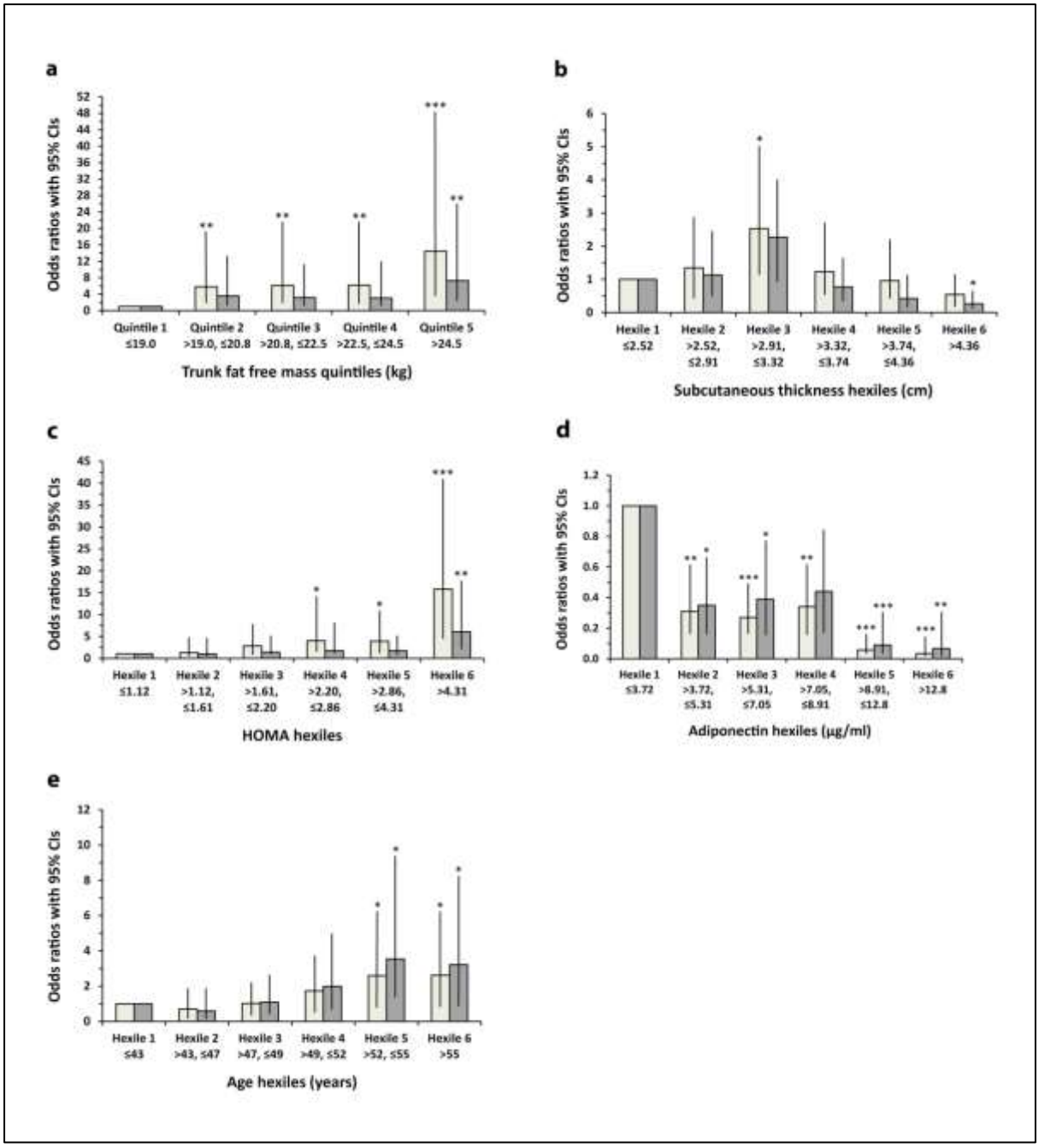


Figure 5.1 legends: Risk of metabolic syndrome across hexiles/quintiles of: A. trunk fat free mass, B. abdominal subcutaneous fat thickness, C. HOMA, D. adiponectin and E. age. Lighter bars represent unadjusted odds ratios whilst darker bars represent odds ratios with adjustment for trunk FFSTM, subcutaneous fat, HOMA, adiponectin, smoking and age; *$p < 0.05$, **$p < 0.005$, ***$p < 0.0005$ vs hexile 1.

5.5 Discussion

This study has shown that in a population of urban African females with a high prevalence of metabolic syndrome and obesity, trunk FFSTM and abdominal subcutaneous adipose tissue increases and reduces the risk, respectively of metabolic syndrome. Further analysis demonstrated that this was due to a positive association of trunk FFSTM with risk of low HDL levels and a negative association of subcutaneous adiposity with risk of impaired fasting glucose. Other risk factors for metabolic syndrome were insulin resistance, age and smoking whilst adiponectin, at all levels across its range, was associated with lower risk. The risk of metabolic syndrome associated with the other variables, specifically at low levels and with the exception of age, was attenuated after adjusting for adiponectin.

Metabolic syndrome was defined in this study without the waist circumference criterium. This was done because the main aim of our study was to isolate risk factors for the metabolic syndrome that were modulators of the cardiometabolic rather than the anthropometric component of the syndrome. There are many CVD risk factors that correlate with waist circumference and therefore it is reasonable to suggest that a number of these factors may associate with metabolic syndrome simply through their relationship with waist circumference. It is also possible that the inclusion of waist circumference within the criteria for metabolic syndrome masks the true relationship of other factors with the cardiometabolic components of the syndrome, as exemplified in the current study for subcutaneous abdominal fat. The definition of metabolic syndrome in our study required the presence of 3 out of 4 of the cardiometabolic components. This ensured that all subjects with the syndrome as defined by our criteria would also have been included in the cohort of subjects defined using the normal harmonised criteria (16) and would have a severe cardiometabolic disease risk profile.

The current study is the first to show that subcutaneous abdominal fat attenuates the risk for metabolic syndrome. The reason that no previous studies have observed this relationship may be due to the fact that it is masked by the inclusion of waist circumference within the criteria for diagnosing metabolic syndrome, as demonstrated in the present study. Thus, subcutaneous abdominal fat is only revealed as protective for metabolic syndrome when waist is removed

from the metabolic syndrome criteria. Furthermore, our data shows that high subcutaneous fat level is related to a lower risk of metabolic syndrome; via the effect of abdominal subcutaneous fat on glucose levels (see Table 5.3). This could possibly be explained by subcutaneous fat acting as a triglyceride reservoir, thus reducing its deposition in visceral fat or at ectopic sites such as muscle, liver, pancreas where lipid deposition leads to increased insulin resistance (382). Furthermore, a recent large, multinational, cross–sectional study has shown that abdominal subcutaneous fat is associated with a lower risk of type 2 diabetes in women (383), and in a study of 73 type 2 diabetic patients, increased superficial subcutaneous abdominal fat was associated with lower HbA_{1c} and fasting glucose levels (384). The present study extends the findings of these earlier investigations, which did not measure subcutaneous fat outside of the abdominal area, and demonstrates that it is specifically the abdominal subcutaneous fat depot that is related to improved glycaemia. It should however be noted that a number of other studies have shown that subcutaneous abdominal fat has a statistically significant positive association with insulin resistance (90, 385, 386). In a univariate regression model this was also observed in the current study. However, addition of waist circumference to the model severely attenuated the relationship to non-significance. This suggests that data within the literature that conflicts with our observations regarding the relationship between subcutaneous abdominal fat and insulin resistance may partly be due to confounding from other variables.

Data from the current study demonstrating that age, smoking, insulin resistance and adiponectin are associated with metabolic syndrome risk are expected, as other studies show similar associations (see Table 5.2) (20, 180, 255, 283). However, the finding that trunk FFSTM was positively associated with both metabolic syndrome and low HDL levels, was not expected. Interpretation of this data is complicated by the fact that the DXA–derived trunk FFSTM measure is a composite of all the soft tissue components of the trunk including muscle and organ mass. It is therefore difficult to determine which of these components is the true causative variable. We hypothesise that ectopic fat deposition within the trunk, which DXA is unable to measure, may be the principle element causing these associations. One of the major components of the trunk region is the liver, and it is known that steatohepatitis is characterised by low HDL levels (387). Future analyses involving a more discriminatory body scanning technique, such as magnetic resonance imaging (MRI), must be undertaken to

test this hypothesis. It is interesting to note that an increased risk of metabolic syndrome with higher whole body FFSTM was observed in a previous study (388), as was an inverse association between HDL levels and non–adipose body mass in both a cross–sectional (389) and a longitudinal study (390). Furthermore, a recent study has shown that ectopic fat deposition in the liver and skeletal muscle has a greater effect on insulin sensitivity in African than European females (391).

Adiponectin appears in 3 of the 4 logistic regression models describing the risk factors for the 4 cardiometabolic components of the metabolic syndrome (see Table 5.3). This demonstrates the wide effect of this adipokine on components of the metabolic syndrome. White South Africans seem to have higher levels of adiponectin compared with the other ethnic groups (33). Little data are available on the role of adiponectin in the aetiology of metabolic syndrome in developing countries (178), but studies of African populations do suggest a protective role of adiponectin against metabolic syndrome (33, 179). Our data also shows that leg fat protects against elevated triglyceride levels. Such an association has been observed in other studies (392, 393) and may be explained by the hypothesis that subcutaneous fat acts to buffer post–prandial triglyceride and free fatty acid levels (382). An interesting finding is the positive effect of smokeless tobacco use (snuff) on HDL levels. One other study performed on traditional smokeless tobacco (snus) use in Sweden, also showed a positive association with HDL levels (394). The mechanism of this association is unknown however, it must be noted that smokeless tobacco formulations differ widely and other studies demonstrate more atherogenic lipid profiles in smokeless tobacco users (395).

Our data shows that for HOMA and trunk FFSTM there is a gradual increase in metabolic syndrome risk across their range (see Figure 5.1) and this trend is attenuated after adjustment for all the other independent variables present in the multivariable logistic regression model for metabolic syndome (see Table 5.2), leaving significant ORs only for the highest hexile/quintile. However, it is adiponectin that is the main cause of the attenuation of risk associated with FFSTM, whilst adiponectin and FFSTM explain the attenuation of metabolic syndrome risk associated with HOMA. This suggests that at lower levels of HOMA and FFSTM adiponectin is a confounder and explains a large proportion of the risk for metabolic syndrome. Furthermore, risk of metabolic syndrome drops dramatically with increasing levels of adiponectin and this effect is margina-lly attenuated by adjustment for the other variables. These results demonstrate that adiponectin across its full concentration range has significant

effect on metabolic syndrome risk and acts independently of the other metabolic syndrome risk factors, whilst HOMA and trunk FFSTM only have independent effects at high levels. Age also has a significant effect on metabolic syndrome risk only at the top end of its range, and this effect is not attenuated by adjusting for the other variables. The risk of metabolic syndrome produced by smoking was also not affected by adjustment for the other variables. With increasing subcutaneous abdominal fat, the OR for metabolic syndrome rose to a peak by hexile 3 and then fell dramatically by hexile 6. This pattern may be due to confounding because adjustment for the other variables from the logistic regression model caused the peak OR at hexile 3 to fall and significance to disappear, whilst at hexile 6 a significant protective effect appeared. Adiponectin and trunk FFSTM were the main contributors to this effect. This emphasises the influence of adiponectin on metabolic syndrome risk at lower levels of abdominal subcutaneous fat but an independent protective effect of subcutaneous fat at high levels. These results also demonstrate the strong effect of trunk FFSTM on metabolic syndrome risk, which may be mediated by ectopic fat, as described previously.

This study demonstrates that for most variables the risk they cause for metabolic syndrome is only observed at the high end of their range, with the risk induced at lower levels mostly due to confounding by other risk factors, most particularly adiponectin. Adiponectin is the only variable that produces significant disease risk across its full range with minimal confounding from other variables. Furthermore, adiponectin modifies metabolic syndrome risk by effects on multiple components of the syndrome i.e. HDL, triglycerides and glucose tolerance. Hypertension is the only metabolic syndrome component that is not modulated by adiponectin or HOMA. This suggests that the aetiology of metabolic syndrome is two–pronged, with insulin resistance–adiponectin being primary aetiological factors for the lipid and glucose sections of the syndrome, whilst age and waist underpin the development of hypertension.

Limitations of this study include its cross–sectional format. Also, abdominal fat levels were not assessed using the gold standard techniques of CT or MRI scanning but rather used ultrasound. However, this method has been favourably validated against MRI (396, 397). A further limitation of this study was the lack of assessment of ectopic fat deposition, particularly within the liver. We did not investigate hypotheses that focussed on one specific association e.g. visceral fat as a principle risk factor for metabolic syndrome. The aim of this study was to uncover possible novel risk factors rather than to focus on risk factors observed

in other studies, the majority of which have not been performed in sub-Saharan African populations. However, this study used a large sample size and measured a wide variety of appropriate variables in a population for whom little data exists on the aetiology of metabolic syndrome. This is the only study to determine how risk for metabolic syndrome varies across the range of each risk factor and how these factors modulate the effect of one another across their ranges. Defining metabolic syndrome without the use of the waist criteria also allowed us to uncover a novel association with subcutaneous abdominal fat that provides valuable new information on the effects of different body tissue compartments on metabolic syndrome risk. This study also highlights the effect of trunk FFSTM on the aetiology of cardiometabolic disease. Finally, alcohol consumption was not captured at this time point, thus we could not control for it in the analyses.

5.6 Conclusions

In conclusion, this study demonstrates that the cardiometabolic components of the metabolic syndrome are favourably modulated by various subcutaneous body fat depots and that trunk FFSTM may have detrimental effects on HDL levels via an unknown mechanism that warrants further investigation. Falling adiponectin levels independently affect multiple components of the metabolic syndrome (HDL, triglycerides and glucose tolerance), significantly reducing metabolic syndrome risk even at the lower end of its range (hexiles 5 and 6). Other risk factors (trunk FFSTM, abdominal subcutaneous fat, HOMA, and age) have prominent effects on metabolic syndrome risk only at the upper end of their range and the effects observed at lower levels are largely due to confounding from adiponectin. The mechanisms by which adiponectin and abdominal subcutaneous fat attenuate metabolic syndrome risk, whilst trunk FFSTM increases risk need to be further investigated and may provide information on novel targets for therapeutic interventions.

PART 3

CHAPTER 6: DISCUSSION AND CONCLUSIONS

6.1 Consolidated findings of the thesis

This thesis set out to investigate the factors associated with cardiometabolic diseases in ageing black South African women living in an urban–setting. The objectives of this thesis and related findings are highlighted in Table 6.1.

Table 6.1: Summary table of objectives and findings

Number	Objectives	Chapter	Key findings
1.	To describe patterns of physical activity in a middle–aged cohort of urban black South African women living in Soweto, Johannesburg	3	• Most women in the study were physically active. • All domains of physical activity were higher in the physically active group compared with the inactive participants (all $p < 0.001$). • Overall sitting time was 180 minutes per day, but did not differ between the activity groups.
2.	To examine the association between socio–economic status and physical activity patterns	3	• Household SES score was inversely associated with time spent walking for travel ($r = -0.10$; $p < 0.01$), but was not associated with any other activity variable. • Participants in the lowest tertile for walking for travel had a significantly higher household SES score compared with women in the middle ($p < 0.05$) and highest ($p < 0.001$) tertiles.
3.	To determine if physical activity is associated with anthropometry and metabolic variables	3	• Total moderate–vigorous physical activity was negatively associated with fasting insulin, and walking for travel was inversely associated with total cholesterol. • Work moderate–vigorous physical activity was positively associated with fat–free, soft–tissue mass. • Sitting time was positively associated with serum triglycerides and diastolic blood pressure.
4.	To describe the change in body composition over a10–year study period in a cohort of urban black South African women.	4	• There was a significant increase in all body composition measures (all $p < 0.001$), with a mean weight gain for the whole sample of 5.17 ± 8.86 kg. • The prevalence of high waist

			circumference (≥ 80cm) and obesity increased (both $p < 0.001$).
5.	To determine whether baseline measurements of body–size dissatisfaction and body–size discrepancy are associated with baseline body composition measures, and correlate with changes in body composition over 10–years of follow–up.	4	• At baseline, women who wanted to be leaner had significantly higher body composition outcomes compared with those with a negative or zero FID score ($p < 0.0005$ for all comparisons). • There were no differences between the FID groups for absolute change in the any of the body composition measures even when this data was expressed as percentage change from the baseline, and when FID negative and zero groups were combined and compared with the FID positive group • With regard to body–size discrepancy at baseline, 74% of the subjects underestimated their actual body–size (negative PAD score), 2% overestimated actual body weight (positive PAD score), and 24% correctly perceived their actual body weight (zero PAD score). • At follow up, the proportion of women in each of the PAD groups were similar to baseline, i.e. 73.5%, 0.70%, and 25.8% respectively. • Women who underestimated actual body weight status had a significantly higher body composition compared with those who overestimated or correctly perceived their actual body weight ($p<0.0005$ for all comparisons). • Women who correctly perceived actual body weight had a significantly greater increase in fat mass than the women who underestimated body weight. • Absolute change in total body fat was lower in those who underestimated body–size when compared with those who accurately assessed body–size. • An underestimation of body–size was negatively associated with absolute change in peripheral adiposity
6.	To determine whether baseline lifestyle factors including diet and physical activity are associated with changes in body composition	4	• Baseline diet was not associated with change in body composition; however, total vigorous physical activity was inversely associated

			with change in BMI, waist, total body fat, and central and peripheral adiposity. • Smoking was associated with a smaller increase in lean tissue over time, while alcohol was inversely associated with change in waist.
7.	To identify the main contributing factors to the cardiometabolic features of the metabolic syndrome in a cohort of urban African women known to have a high prevalence of obesity and metabolic syndrome	5	• In a multivariable logistic regression model, trunk FFSTM, HOMA, adiponectin, subcutaneous fat thickness, age and smoking were associated with the cardiometabolic features of the metabolic syndrome.
8.	To determine how disease risk varied across the range of levels of each risk factor	5	• For each trunk FFSTM quintile, the unadjusted ORs for metabolic syndrome are significant. • The unadjusted ORs for metabolic syndrome in the subcutaneous fat model are only significant in hexile 3. • The analysis of HOMA hexiles showed that metabolic syndrome risk increases progressively from hexile 1 to 6, with hexiles 4–6 showing statistically significant ORs. • The unadjusted ORs for metabolic syndrome in the adiponectin model decrease from hexile 1 to 2, plateau until hexile 4 and then drop in hexile 5 with the lowest point at hexile 6. All ORs are significantly different compared with hexile 1. • Age hexiles increase steadily from hexile 1 to 6, with significant ORs at hexile 5 and 6.
9.	To examine whether each risk factor modulated the contribution of the other factors to disease risk across their range	5	• After adjustment for all the other variables, only quintile 5 in the trunk FFSTM model remained significant. Adiponectin was responsible for attenuating the risk. • After adjustment for the other variables, hexile 3 became non–significant in the subcutaneous fat model, while hexile 6 showed a significantly lower OR compared with hexile 1. These changes in the ORs were mainly due to trunk FFSTM and adiponectin. • In the analysis of adjusted HOMA hexiles, only hexile 6 remains significant. The main contributor to this effect was the combination of

			trunk FFSTM and adiponectin. • After adjustment the ORs for the adiponectin model increase slightly but only hexile 4 becomes non–significant. • After adjustment, age hexile ORs are similar to unadjusted ORs.
10.	To determine which individual components of the metabolic syndrome were influenced by each of the risk factors	5	• Visceral fat, HOMA, age, and smoking are associated with an increased risk of high serum triglyceride levels, whilst adiponectin and leg fat are associated with reduced risk. • Snuff use and adiponectin are associated with a reduced risk of low HDL levels, whereas trunk FFSTM is associated with a higher risk. • Adiponectin and subcutaneous adipose fat reduce the risk of impaired fasting glucose, whereas age and HOMA increase the risk. • Age and waist circumference are each associated with an increased risk of hypertension.

6.2 Emerging scientific areas from the results:

6.2.1 The increasing prevalence of obesity and cardiometabolic diseases in urban–dwelling, black South African women with age

Our data has shown that obesity and related cardiometabolic diseases are common in this cohort of black South African women, and these diseases increase with age. Obesity in this study population was also related to non–classical risk factors. For example, the psycho–social processes surrounding body–size perception in African women seems to be changing. This thesis highlights the existence of one obese group of women content with body–size, while another group of obese women had a desire to be thinner. In the diverse South African society, this finding might be important for obesity interventions in black South African women. Moreover, the fact that the traditional acceptance of large body size is being challenged from within this ethnic group, indicates that plans to address weight gain might be welcomed by ageing obese Africans. Our data suggests that focussing on walking as a means of addressing the obesity pandemic might be beneficial, particularly as most participants walked for travel. However, some studies have documented that walking is seen as a chore and not leisure, suggesting that the acceptability of walking as recreational physical activity

needs to be explored further in African society. The actual intensity of the walking was not captured. Therefore, once the intensity of the walking is known, public health interventions toward obesity could encourage walking to work at a moderate–vigorous pace in a greater number of this population. However, it should be noted that the unemployment rate in this cohort is high (42.4%) and therefore alternative mechanisms would be required in those without jobs e.g. encourage walking in other spheres of their daily routine.

6.2.2 Understanding the physiological and contextual mechanisms behind the high prevalence of obesity and cardiometabolic diseases

6.2.2.1 The physiological mechanisms relating to metabolic syndrome in African females

Previous studies of women have speculated what the contributing factors of metabolic syndrome were; and until now very little data has been available on the proposed aetiology of this disease, particularly in a cohort of African females with a very high level of obesity. This multi–faceted syndrome and the fact its individual components can each have unique risk factors may be the reason for the lack of understanding regarding its underlying causes. We have attempted to determine some of the body composition and metabolic causes of the syndrome in this thesis.

We have shown that low abdominal subcutaneous fat is associated with higher risk of metabolic syndrome, because of its interaction with blood glucose. A more robust investigation of the data shows that even at low levels of abdominal subcutaneous fat, an association with metabolic syndrome is still evident. A possible explanation could be that the subcutaneous fat compartment acts a metabolic reservoir protecting the abdominal region from primary deposition of fat around the central organs. However, once this site has reached its capacity for fat deposition, then visceral and ectopic fat deposition increases. However, within our study we found that visceral fat was not a risk factor for metabolic syndrome and correlated with only one of the components of the syndrome i.e. triglycerides. The reasons for these findings are not known, however studies have shown that visceral fat levels in back African subjects are lower than in subjects of European ancestry (92) and visceral fat does not correlate with insulin sensitivity in the former population but does in the latter (90). These data therefore suggest that visceral adiposity is not as important a cardiometabolic disease

risk factor in Africans as in other population groups. Another interesting finding is the inverse association of leg fat with high triglycerides. Thus, subcutaneous fat in the abdominal and gluteofemoral regions are associated with glycaemic control and optimal metabolism of triglycerides, respectively.

Our data has shown that the risk factors for metabolic syndrome are attenuated when adjusted for each other. Thus, adiponectin explains most of the weakening of the relationship between the risk factors in metabolic syndrome. So at every level of those risk factors, the risk produced by that risk factor is actually due to adiponectin and most of these risk factors only increase the risk of metabolic syndrome in their highest level, but at the lower level of those risk factors it is adiponectin that is the main contributor. Visceral adipose tissue and insulin resistance are the main determinants of adiponectin in African Americans (398). Insulin resistance is also a key predictor of adiponectin in Cameroonian women (399). However, body fat was observed to be a determinant of adiponectin in African women and not the African American women. The reason for the discrepancy could be explained by the use of waist circumference as a crude measure of intra-abdominal adiposity rather than visceral adiposity in the Cameroon study. However, black South Africans have comparable visceral adipose tissue to African Americans (90-92), suggesting that the determinants of serum adiponectin are similar. Finally, our data shows that adiponectin is an important contributing factor and this adipokine explains risk of metabolic syndrome in African women, independent of insulin resistance.

6.2.2.2 African females in an urban, obesogenic context

South Africa has transitioned out of a system of government sanctioned inequality fairly recently. While the new regime promises to elevate the socio–economic status of the black majority, inequality is still evident today and most black Africans live in poverty stricken, obesogenic environments (400). Consumer demand for cheap, calorie dense foods are common amongst this population group (237) and most African women are classified as sedentary despite attaining the recommended weekly amount of physical activity (41). Most women in this study have access to sedentary promoting products e.g. ownership of motor vehicles, and monthly subscription to satellite television; despite their high cost. This phenomenon exists in the presence of high unemployment and low high school completion.

Thus, South Africa is experiencing a dual transition, one of global urbanisation and its accompanying negative impact on the well–being of ageing women, and one of socio–political change which aims to reduce poverty in black South Africans (401). Both of these transitions seem to have an influence on the health status of black South African women. The primary reason for urbanisation is access to employment and higher perceived economic status compared with the rural lifestyle. However, settlement in urban areas is usually accompanied by the adoption of westernised behaviours. We have shown that the prevalence of obesity and its related metabolic disorders is very high in this urban population. The emergence of these diseases has developed despite most women in the cohort achieving more than the WHO recommended amount of daily physical activity. The consumption of high–fat foods did not have an influence on the body composition outcomes in this study population. Our data suggest that higher intensity physical activity protects against fat accumulation and the risk of cardiometabolic diseases. We have also shown that walking as a means of transport is the most prominent method of physical activity in black South African women. This form of physical activity is cost–effective and thus important to include in an obesity intervention in African populations.

The prevalence of tobacco smoking in this study population is low, which is comparable to the national and international incidence of smoking in women (23, 202). We have nevertheless shown that smoking is associated with decreased lean tissue and increased risk of metabolic syndrome. The low prevalence of tobacco consumption is partially due to the stringent regulations surrounding the sale and marketing of tobacco products in South Africa. On the other hand, cigarette smoking is also expensive and thus not affordable to most people. The presence of smokeless tobacco (snuff) was significantly higher compared with tobacco smokers. The potential protective effect of smokeless tobacco against low HDL levels was shown in this study. South African smokeless tobacco products are however not regulated, and are addictive because of the high nicotine content (304). The consumption of these products is therefore of public health concern and the positive effect of snuff use on HDL levels requires further investigation.

Alcohol use in this study population is similar to that of smoking. Central adiposity decreases over time in those women who consume a higher frequency of alcohol. However, the chronic use of alcohol is associated with progressive physiological damage of essential organs, and increases the risk of future organ transplantation and heavy reliance on lifelong chronic medication (402). Therefore despite the positive effects of modifiable lifestyle behaviour risk factors shown in this study, adherence to poor health choices may result in increased metabolic syndrome risk and early morbidity.

6.3 Theoretical relevance

South Africa is in the midst of epidemiological transition with most of the inhabitants living in urban settings. City life is economically appealing, however most South Africans living in urban areas are poor and have a high prevalence of cardiometabolic diseases (76, 223). We have shown that the prevalence of obesity, metabolic syndrome and their accompanying components in black South African women is high. Our findings add to the few data available on the contributing factors associated with cardiometabolic diseases in African women.

The initial conceptual framework discussed in Chapter 1 (Fig.1.2) highlighted the possible associations of risk factors of obesity and metabolic syndrome. The findings of this thesis require that the original conceptual framework be modified (Fig. 6.1). No studies have shown the impact of body–size discrepancy on long–term body composition changes in African populations. Psycho–social factors were significantly associated with lower changes in adiposity, thus have been added into the modified framework. Likewise, data are conflicting regarding the association of socio–economic factors with body composition in developing countries; however we have confirmed a significant direct association between socio–economic status and body fat in this study population.

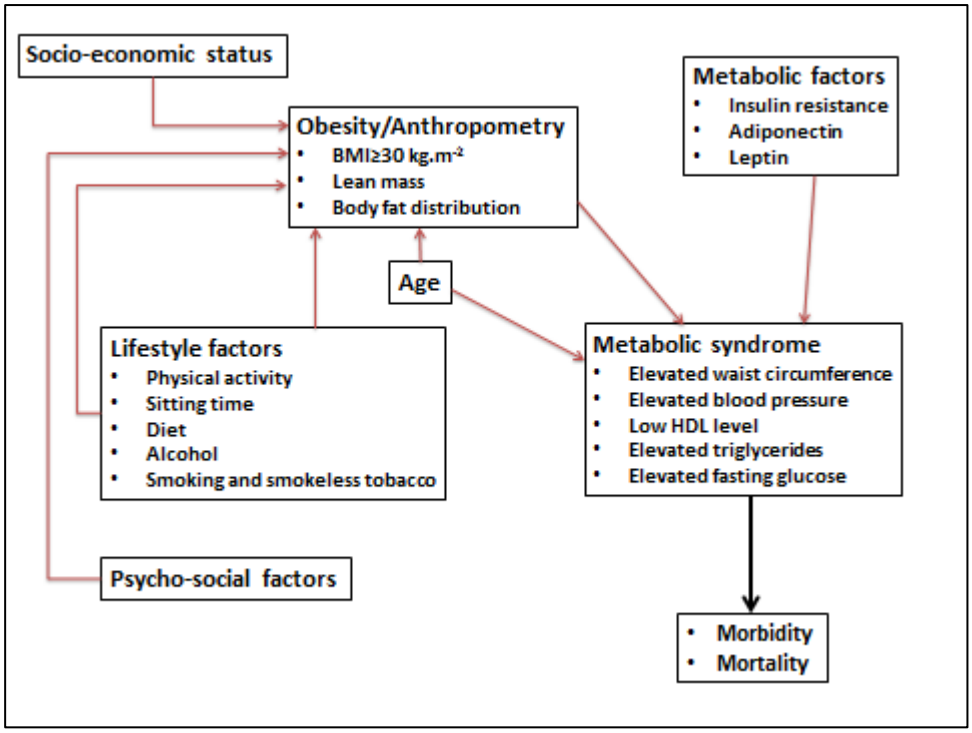


Figure 6.1: Modified conceptual framework. Evidence to strengthen the hypothesised associations proposed in the beginning of the thesis have been confirmed, and are therefore represented with solid red lines.

The addition of smokeless tobacco/snuff to the model is novel. We have shown that the consumption of snuff in black South African women is high, and the inverse association of snuff with low HDL suggests a protective role against dyslipidaemia. Another interesting finding was the protective effect of adiponectin with the cardiometabolic components of metabolic syndrome, suggesting that higher concentrations of this hormone reduce the risk and future onset of metabolic syndrome.

Insulin resistance was associated with metabolic syndrome as anticipated; however, the inverse association of subcutaneous adipose tissue with impaired fasting glucose was unexpected. Similarly, the significant association of trunk FFSTM with metabolic syndrome via its association with low HDL was also not foreseen.

Age was significantly associated with a number of cardiometabolic disease risk factors. We have observed that age is also associated with a lower change in fat–free, soft–tissue mass, suggesting a link between chronological age and sarcopenia in African women. Importantly,

active smoking seems to exacerbate this relationship. This fact could be crucial for future public health interventions targeting tobacco consumption in ageing black South African women. Finally, the association of waist circumference with components of metabolic syndrome emphasise the importance of including regular moderate–vigorous physical activity as part of a lifelong plan to decrease cardiovascular disease risk as depicted in Figure 6.1. The modified conceptual framework also highlights the interrelatedness of various risk factors, demonstrating the complexity surrounding the pathogenesis of metabolic syndrome in African women.

6.4 Contextual relevance, local and national

Our longitudinal findings have confirmed that the prevalence of obesity and related diseases has increased in black South African women living in Soweto. Lifestyle behaviours were confirmed to have an influence on these diseases. This thesis could therefore assist policy makers involved in addressing obesity in African populations, particularly emphasising the influence of physical activity and the domain of walking as means of transport as a protective mechanism against the onset of cardiometabolic diseases. However, the intensity of the walking physical activity domain was not determined in this study, and most of the study participants had a high proportion of sitting time, which could partly explain the high prevalence of obesity. Thus, as most participants already walked, it would probably be more beneficial to focus on targeting sitting time. It was also observed that the underlying factors associated with obesity and metabolic syndrome in African women are multi–faceted and complex, suggesting that a holistic, integrated approach is necessary to dealing with these disorders.

Our findings also demonstrate that the traditional African belief system around body–size preference is changing. There seems to be a co–existence of belief patterns within black South Africans with our data showing the presence of various groups, i.e. preference for the traditional obese body–shape, thinness, or contentment with present body–size. These data suggest that future obesity interventions undertaken by policy makers in South Africa should recognise the cultural beliefs around body shape.

6.5 Limitations and advantages

Specific limitations are mentioned in the papers, but a significant limitation for the thesis was that dietary patterns of the study population were not included in the analyses. Therefore, we are potentially missing another important piece of the puzzle around modifiable lifestyle factors. However, this data has been collected and will be part of subsequent analyses post–PhD.

There are a number of advantages of this thesis which will be listed:

- I was fortunate to be able to draw on 10 years of secondary and prospective data from the Bt20 study.
- The sample was large enough to be representative of black South African women living in Soweto, Johannesburg, which is an urban–setting undergoing rapid urbanisation.
- Access to an established network of research entities allowed the researcher to collect body composition and biochemical data using advanced equipment and standardised laboratory methods. This allowed for the comprehensive analysis of a multitude of risk factors and covariates associated with metabolic syndrome.
- The process of data collection was made manageable with the help of a professional team of multi–lingual research assistants. The translation of information into the participants' home language where necessary ensured that all participants understood all aspects of the study, allowing them to share information and complete the questionnaires correctly.

6.6 Recommendations for further research

6.6.1 Further research regarding body–size dissatisfaction and body–size discrepancy in African women

The findings of this thesis could lead to questions around obesity interventions in African women experiencing acculturation. Therefore in an experimental study design, baseline anthropometric, psycho–social and metabolic measurements should be determined. An intervention of supervised moderate–vigorous exercise should be performed to determine whether baseline anthropometric, metabolic and psycho–social variables change over time as a result of regular physical activity. It would also be advantageous to measure compensation and sedentary time. These data will be compared to a closely matched, non–physically active control population. This information may assist future attempts at reducing obesity in black South African women.

We also assumed that participants in this study would prefer a larger body size because of traditional African ideals which associate obesity with prosperity and other beneficial aspects (5, 67, 70). However, comparison with women from other South African ethnic groups is important to determine whether preference for higher body size is limited to black Africans or wider acculturation is taking place.

6.6.2 The role of diet in obesity

Research indicates that the consumption of sugar sweetened beverages has increased globally and is associated with weight gain, type 2 diabetes and metabolic syndrome (403, 404). Soft 'carbonated' drinks and canned fruit juices can have up to 45 g of added refined sugars (330 ml serving), essentially increasing the daily average calorie intake, which may translate into further cardiometabolic risk. There are a number of potential research studies involving dietary behaviour that should be performed in African women:

- Firstly, the research into the dietary behaviour patterns of African women are limited, implying that baseline and follow–up data are needed.

- Secondly, studies conducted in the South African context can attempt to determine if interventions such as cognitive behavioural therapy, increased physical activity, reduced caloric intake or a combination of these alter the cardiometabolic risk associated with obesity in African women.
- Thirdly, analysis of these interventions is needed to determine whether they influence the body–size dissatisfaction and body–size discrepancy patterns of black South African women living in urban settings.
- Fourthly, an investigation of the impact of socio-economic status on dietary intake and food security.

6.6.3 To determine cut–points of cardiometabolic diseases in an ethnically diverse society

Waist circumference is used as a proxy measure of central adiposity in the identification of metabolic syndrome, and recent data suggests there is a need to use a more appropriate waist cut–point for black African women (4). A continuation of this valuable study would be to explore whether the current cut–points used to diagnose the cardiometabolic components are appropriate for an African population. Receiver operator curve analysis can be used to determine ethnic–specific cut–points. Moreover, further longitudinal studies are required to fully understand the factors associated with metabolic outcomes in ageing African women.

6.6.4 Trunk fat–free, soft–tissue mass

From the findings of the thesis, we speculated an association of trunk FFSTM with metabolic syndrome, however, given the limitation of the use of DXA to determine body composition in the truncal region, we would like to confirm this relationship using MRI to determine which component of trunk FFSTM is the true modulator of HDL levels.

6.6.5 Objective measurements of physical activity and sedentary behaviour

The objective measurement of physical activity and sedentary behaviour would provide more robust information of physical activity patterns and sedentary time in African populations, particularly as Western cultures seem to underestimate sedentary behaviour (405) and overestimate physical activity time (406).

6.7 Conclusions

This thesis highlighted some of the elements associated with obesity and associated cardiometabolic diseases in a population of African females with a high prevalence of metabolic syndrome. Our findings suggest that obesity interventions focus on lifestyle behaviour change to address the obesity pandemic in female African populations, particularly physical activity, sitting time, and snuff use. The prevalence of snuff consumption was high, however further studies are required to determine whether the association with HDL is true, and if it has any negative health consequences in this population.

A positive association of trunk FFSTM with the risk of high HDL levels was observed and requires further investigation, as does the negative association of subcutaneous abdominal fat with the risk of elevated glucose levels. Finally, our findings display the protective influence of adiponectin against metabolic syndrome and its components, suggesting that this adipokine has a key role in the aetiology of metabolic syndrome in African women.

The findings of this thesis show that the majority of urban black South African women have a high prevalence of obesity and cardiometabolic disease risk factors despite being classified as 'physically active'. However, the intensity of the respective domains of physical activity is unknown. As walking as a means of travel/transport is a major contributor to physical activity, future research should attempt to determine whether the intensity of this activity plays a role in the prevention of cardiometabolic diseases. It was also demonstrated that an

underestimation of body–size is common and is associated with a lower gain in total body adiposity and a desire to lose weight in most of the participants.

Finally, this thesis observed that adiponectin has a significant protective role against metabolic syndrome that is independent of other risk factors. The protective and augmentive effects of abdominal subcutaneous fat and lean trunk mass, respectively, on metabolic syndrome risk demonstrate the existence of novel interactions between body composition and cardiometabolic disease.

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APPENDICES

APPENDIX 1: ETHICAL CLEARANCE CERTIFICATE

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG
Division of the Deputy Registrar (Research)

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)
R14/49 Mr Phillippe Jean-Luc Gradidge

CLEARANCE CERTIFICATE	**M110627**
PROJECT	Factors Associated with Obesity and Metabolic Syndrome in an Ageing Cohort of Black Women Living in Soweto Johannesburg (Study of Women in
and	Entering Endocrine Transition (SWEET))
INVESTIGATORS	Mr Phillippe Jean-Luc Gradidge,
DEPARTMENT	Department of Paediatrics/Bt20
DATE CONSIDERED	24/06/2011
DECISION OF THE COMMITTEE*	Approved unconditionally

Unless otherwise specified this ethical clearance is valid for 5 years and may be renewed upon application.

DATE 22/07/2011 **CHAIRPERSON** .....
(Professor PE Cleaton-Jones)

*Guidelines for written 'informed consent' attached where applicable
cc: Supervisor : Prof Shane Norris

DECLARATION OF INVESTIGATOR(S)

To be completed in duplicate and **ONE COPY** returned to the Secretary at Room 10004, 10th Floor, Senate House, University.
I/We fully understand the conditions under which I am/we are authorized to carry out the abovementioned research and I/we guarantee to ensure compliance with these conditions. Should any departure to be contemplated from the research procedure as approved I/we undertake to resubmit the protocol to the Committee. **I agree to a completion of a yearly progress report.**

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES...

APPENDIX 2: CAREGIVER INFORMATION SHEET

Developmental Pathways to Health Research Unit (DPHRU)

Department of Paediatrics, School of Clinical Medicine, Faculty of Health Sciences, Wits

Study title: Factors associated with obesity and metabolic syndrome in an ageing cohort of black women living in Soweto, Johannesburg (Study of Women in and Entering Endocrine Transition [SWEET])

Greeting: Hi, my name is Philippe Gradidge and I'm studying a PhD at the University of the Witwatersrand (Wits).

Introduction: I am doing research on obesity and metabolic syndrome. The purpose of the study is learn more about what causes obesity and metabolic syndrome in ageing black women.

Invitation to participate: I am requesting your permission to volunteer as a participant in this study.

What is involved in this research study: We will ask you to give us some information about your general health and lifestyle, and we will do a questionnaire with you regarding your menstrual cycle, your physical activity, recreation activity, food frequency, and attitude towards obesity. We will be taking some routine measurements (such as your weight, blood pressure, height etc.). We will conduct a bone X-ray (DXA scan) to look at your body composition. We would like to take a blood sample to test for different hormones and to see whether you have any health risks. You should only feel a slight prick but if you want EMLA cream can be applied on request. EMLA cream is a topical anaesthetic cream that numbs the area where blood will be pulled so as to minimise discomfort. The results of these tests will be confidential, but we will notify you if we see any health problems. If you would like know your results any way please notify a member of the team.

Risks: There are no risks involved in this research because the processes are non-evasive.

Benefits: There are no direct benefits to the participants involved in the study.

Participation is voluntary: Participation in this study is voluntary and you may withdraw at any time without any penalty or loss of benefits.

Reimbursements: You will be provided with R50 for transport as well as a sandwich and fruit juice.

Time commitment required: There data collection process will take approximately 6 to 7 hours to complete.

Confidentiality: All data collected for this study will be kept strictly confidential. No personal information will be made publicly known. Data collected will be analysed as a group and not individually.

Contact details of researchers: Please contact, Philippe Gradidge (011 717 3363) for any queries and/or further information regarding the study.

Contact details of REC administrator and chair - Rene Wills can also be contacted for any questions regarding the study ethics at 011 274 9278.

Your participation in this study is greatly appreciated. If you are happy to participate in this study, kindly read and sign the attached consent form.

APPENDIX 3: CAREGIVER INFORMED CONSENT

Caregiver informed consent

I agree to myself being a participant in the SWEET study, a sub-study of Birth to Twenty

The goals and methods of SWEET study are clear to me.

I understand that the study will involve interviews. All the details and purposes of this study have been explained to me. I understand that I have the right to refuse to participate in the study.

I agree to participation in the study on the condition that:

I can withdraw from the study at any time voluntarily and that no adverse consequences will follow on withdrawal from the study.

I have the right not to answer any or all questions posed in the interviews and not to participate in any or all of the procedures / assessment.

The University of the Witwatersrand Human Ethics committee has approved the study protocol and procedures.

All results will be treated with the strictest confidentiality.

Only group results, and not my individual results, will be published in scientific journals and in the media.

The SWEET study scientific team are committed to treating participants with respect and privacy through interviews conducted in private and follow-up counselling available on request.

I will receive a referral note to a health service if any result is out of the normal range or a problem is detected in the course of the study.

PARTICIPANT (Caregiver)

Printed Name	Signature / Mark or Thumbprint	Date and Time

RESEARCH ASSISTANT:

Printed Name	Signature	Date and Time

APPENDIX 4: ANTHROPOMETRIC MEASUREMENTS

Anthropometry/Measurements

DATE: Day ☐☐ Month ☐☐ Year ☐☐☐☐

Birth to Twenty ID NUMBER: ☐☐☐☐☐☐☐☐

Measurements

- Standing height (mm): ☐☐☐☐
- Weight (kg): ☐☐☐☐
- Waist circumference (mm): ☐☐☐☐
- Hip circumference (mm): ☐☐☐☐

Blood pressure

	(1)	**(2)**	**(3)**
Systolic BP:	☐☐☐	☐☐☐	☐☐☐
Diastolic BP:	☐☐☐	☐☐☐	☐☐☐
Pulse:	☐☐☐	☐☐☐	☐☐☐

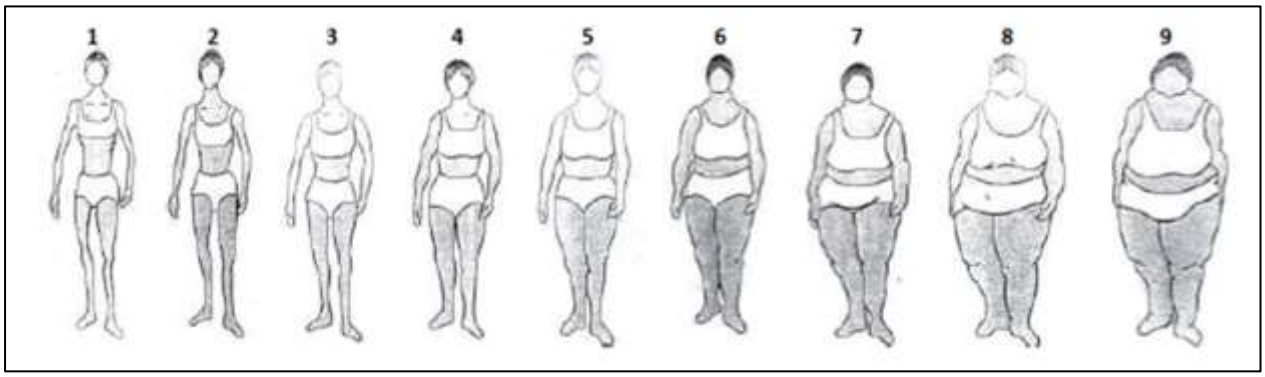
Research assistant name:		Date:	

APPENDIX 5: GLOBAL PHYSICAL ACTIVITY QUESTIONNAIRE

PHYSICAL ACTIVITY (Modified STEPs Core data set) *The next questions are about the time you spend doing different types of physical activities. This includes activities you do at home, at work, travelling from place to place and during your spare time. You are requested to answer the questions even if you don't consider yourself to be an active person.*		
Occupation-related Physical Activity (paid or unpaid work): *When answering the following questions, think back over the **past 12 months** and consider (think of) **a usual week**:*		
1	Does your work involve <u>mostly</u> sitting or standing still, **OR** walking for very short periods (less than 10 minutes)?	YES ..... 1 NO ..... 2 (*If Yes, go to 4)*
2a	Does your work involve <u>vigorous</u> activities, (<u>like</u> heavy lifting, digging, or heavy construction) for **at least 10 minutes** at a time?	YES ..... 1 NO ..... 2 (*If No, go to 3a)*
2b	In **a usual week**, how many days do you do <u>vigorous</u> activities as part of your work?	DAYS_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _
2c	On a usual day on which you do <u>vigorous</u> activities, how much time do you spend doing such work?	_____ HOURS _____ MINUTES
3a	Does your work involve <u>moderate-intensity</u> activities (<u>like</u> brisk walking or carrying light loads) for **at least 10 minutes** at a time?	YES ..... 1 NO ..... 2 (*If No, go to 4)*
3b	In **a usual week**, how many days do you do <u>moderate-intensity</u> activities as part of your work?	DAYS_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _
3c	On a usual day on which you do <u>moderate-intensity</u> activities, how much time do you spend doing such work?	_____ HOURS _____ MINUTES
4	How long is your usual workday?	_____ HOURS _____ MINUTES
Travel-related Physical Activity: *Other than activities that you've already mentioned; I would like to ask you about the way you travel to and from places (to work, to shopping, to market, to church, etc).*		
5a	Do you walk or use a bicycle (pedal cycle) for **at least 10 minutes** at a time to get to and from places?	YES ..... 1 NO ..... 2 (*If No, go to 6)*
5b	In **a usual week**, how many days do you walk or cycle for at least 10 minutes to get to and from places?	DAYS_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

5c	On a usual day, how much time do you spend walking and cycling for travel	_____ HOURS _____ MINUTES
Non-work related and leisure time Physical Activity: *The next questions ask about activities you do in your leisure or spare time, for recreation or fitness. Do not include the physical activities you do at work or for travel already mentioned*		
6	In your leisure or spare time do you do any vigorous or moderate-intensity physical activity lasting **more than 10 minutes** at a time?	YES ..... 1 NO ..... 2 (*If No, go to 9)*
7a	In your leisure or spare time, do you do any vigorous activities (like running or strenuous sports, weightlifting) for **at least 10 minutes** at a time?	YES ..... 1 NO ..... 2 (*If No, go to 8a)*
7b	IF YES, in **a usual week**, how many days do you do vigorous activities as part of your leisure or spare time?	DAYS_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _
7c	How much time do you spend doing this on a usual day?	_____ HOURS _____ MINUTES
8a	In your leisure or spare time, do you do any moderate-intensity activities (like brisk walking, cycling or swimming) for **at least 10 minutes** at a time?	YES ..... 1 NO ..... 2 (*If No, go to 9)*
8b	IF YES, in **a usual week**, how many days do you do moderate-intensity activities as part of your leisure or spare time?	DAYS_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _
8c	How much time do you spend doing this on a usual day?	_____ HOURS _____ MINUTES
Sitting / Resting Activity: Now I would like to ask you about the time spent *sitting or resting, not including sleeping, **in the past 7 days**. This may include time sitting at a desk, visiting friends, reading, or sitting down to watch television **during working hours and leisure or spare time**.*		
9.	Over the **past 7 days**, how much time did you spend sitting or reclining (lying) on a **usual day (exclude sleeping)**?	_____ HOURS _____ MINUTES

APPENDIX 6: BODY–SIZE DISCREPANCY



1. Which one of the body image silhouettes looks the most like your body?
2. Which one of the body image silhouettes would you like your body to look like?

APPENDIX 7: CONSUMPTION OF HIGH–FAT FOODS, SMOKING, ALCOHOL AND WEIGHT MANAGEMENT

1. Which of the following do you usually eat most of the time?

	None	Yes
Chicken (with skin)		
Red meat (fatty cuts)		
Fried eggs		
Fried fish		
French fries		
Full cream milk		
Processed meats		
Crisps		
Margarine spread on bread		
Butter on bread		

2. Have you ever smoked?

No	Yes

If yes, do you currently smoke?

No	Yes

3. Do you use snuff?

No	Yes

4. How would describe your alcohol intake?

None	Less than 1 drink per day	1–3 drinks per day	>3 drinks per day

5. How often during the past 2 years have you tried to lose weight (mark one only)

0 time	1 time	2 times	3 or more times

APPENDIX 8: SOCIO–ECONOMIC INFORMATION

1. Which one of the following do you have in your household at the present time?

	Yes	No
Electricity		
Television		
Radio		
Motor vehicle		
Fridge		
Washing machine		
Telephone		
Video machine		
Electronic media network (MNET)		
Satellite television (DSTV)		
Cellular telephone		

2. What is your current level of formal education (mark one)?

None	
Grade 1	
Grade 2	
Grade 3	
Grade 4	
Grade 5	
Grade 6	
Grade 7	
Grade 8	
Grade 9	
Grade 10	
Grade 11	
Grade 12	
Tertiary education	

3. Are you currently employed?

No	Yes

3.1. If yes, what type of employment?

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4. What is your current level of formal education (mark one)?

APPENDIX 9: PUBLICATION–Patterns, levels and correlates of self–reported physical activity in urban Soweto women

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http://www.biomedcentral.com/1471-2458/14/934

BMC Public Health

RESEARCH ARTICLE Open Access

Patterns, levels and correlates of self-reported physical activity in urban black Soweto women

Philippe Jean-Luc Gradidge[1*], Nigel J Crowther[3], Esnat D Chirwa[2], Shane A Norris[2] and Lisa K Micklesfield[2]

Abstract

Background: Urban black South African women have a high prevalence of non-communicable diseases such as obesity and type 2 diabetes. The aim of this study was to assess the physical activity patterns of a cohort of middle-aged urban-dwelling black African women and to determine if physical activity is associated with anthropometric measures and metabolic outcomes in this population.

Methods: Physical activity and sitting time were assessed using the Global Physical Activity Questionnaire (GPAQ) in a cross-sectional study of 977 black African women (mean age 41.0 ± 7.84 years) from the Birth to Twenty study based in Soweto, Johannesburg. Anthropometric outcomes were measured and fasting blood glucose, insulin and lipid profile were analysed to determine metabolic disease risk and prevalence.

Results: Sixty-seven percent of the population were classified as active according to GPAQ criteria, and the domain that contributed most to overall weekly physical activity was walking for travel. Only 45.0% of women participated in leisure time activity. The prevalence of metabolic syndrome in this sample was 40.0%, and the prevalence of overweight and obesity was 29.2% and 48.0%, respectively. Women who reported owning a motor vehicle walked for travel less, and participated in more leisure-time activity (both $p < 0.01$), while women who owned a television reported significantly lower moderate-vigorous physical activity (MVPA), and walking for travel (both $p < 0.01$). Sitting time (mins/wk) was not different between the activity groups, but was associated with triglycerides and diastolic blood pressure. Total physical activity was inversely associated with fasting insulin, and physical activity in the work domain was associated with fat free soft tissue mass.

Conclusions: The findings of this study show that the majority of urban dwelling black South African women are classified as physically active despite a high prevalence of obesity and metabolic disease risk factors. Sitting time had detrimental effects on both triglyceride levels and diastolic blood pressure whilst total physical activity attenuated fasting insulin levels. As walking for travel is a major contributor to physical activity, future research should attempt to determine whether the intensity of this activity plays a role in the prevention of cardiometabolic diseases.

Keywords: Physical activity, Sitting time, Women, Black African, Cardiometabolic disease, South Africa

Background

South Africa is a middle income country experiencing epidemiological transition due to rapid urbanisation. Nearly two thirds of the population live in urban areas, with the urban poor carrying the greatest risk of mortality from modifiable non-communicable diseases (NCD) [1-3]. Physical inactivity is accepted as one of the key chronic disease risk factors with 2008 estimations showing that physical inactivity was responsible for approximately 9% of deaths globally [4], however data on its prevalence within developing countries are sparse [5].

South Africa is estimated to be the third most physically inactive country in Africa, with more than half of the population being physically inactive (51.1%) [4]. Studies have shown that South African women are more inactive than men [5,6], suggesting that they may be at a higher risk for chronic diseases resulting from physical inactivity [7]. A study from the South African Comparative Risk Assessment Collaborating Group has shown

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that in adult South African women, an estimated 27.7% of colon cancer, 22.7% of ischaemic strokes, 20.1% of type 2 diabetes mellitus, 30.5% of ischaemic heart disease, and 16.5% of female breast cancer are attributed to inactivity [8]. Black women in South Africa have the highest prevalence of obesity [9], which may partly be influenced by socioeconomic status [10], but may also be related to physical activity since it has been observed that black females in South Africa have significantly less total energy expenditure than white women [11]. Urban dwelling black South African females have recently been confirmed to be less physically active than rural women who usually accumulate higher levels of physical activity by participating in subsistence related activity and walking [12]. Data from the Transition and Health during Urbanisation of South Africans (THUSA) study has shown that physical inactivity is associated with obesity outcomes in black South African women [13]. Sitting time, a proxy measurement for sedentary behaviour, increases the risk for all-cause mortality independent of physical activity time [14]. Only a few studies have reported the estimated prevalence of sedentary behaviour in black South African females [12,15]. These studies showed that rural women were significantly more sedentary than rural men [15], and that urban women were significantly more sedentary than rural women [12].

We hypothesise that urban, black African females have a high prevalence of obesity and metabolic disease both of which are associated with physical inactivity. Therefore, the aim of this study was three-fold: (i) to describe patterns of physical activity in a middle-aged cohort of urban black South African women who have recently been shown to have a high prevalence of metabolic syndrome and related disorders [16]; (ii) to examine the association between socio-economic status and physical activity patterns in this cohort; and (iii) to determine if physical activity is associated with anthropometry and metabolic variables.

Methods

Study population

The study design was cross sectional, and included black African women, who have previously been shown to have a high prevalence of metabolic syndrome, living in an urban setting (Soweto, Johannesburg) [16]. The participants were caregivers from the Birth to Twenty cohort study (Bt20), which began in 1990 when 3273 participants were enrolled to investigate the health and development of children [17]. Bt20 also monitored the health of their biological mothers or caregivers. Participants for this study were included if they answered the Global Physical Activity Questionnaire (GPAQ) and excluded if they were from other ethnic groups, or younger than 18 years of age. The final sample size was 977 which represented 78% of the black African caregivers from the original population of caregivers, and of whom 71.8% were biological mothers. Ethical clearance was obtained from the Human Research Ethics Committee at the University of the Witwatersrand (M010556).

Anthropometric measures

Total body weight (kg) was measured to the nearest 0.1 kg using a digital weighing scale (Dismedinc., Anjou, Canada) and standing height was measured to the nearest mm using a wall stadiometer (Holtain Ltd., Crosswell, UK). The participants wore minimal clothing and did not have shoes on during the measurements. Trained research assistants conducted the measurements, and the coefficients of variation for body weight and standing height measurements were both <1%.

Body mass index (BMI, $kg.m^{-2}$) was calculated and classified as normal (≥18.5 and < 25 $kg.m^{-2}$), overweight (≥25 and < 30 $kg.m^{-2}$) or obese (≥30 $kg.m^{-2}$) [18]. Using a flexible, but inelastic measuring tape, a measurement of the waist circumference was taken at the narrowest part of the trunk, horizontally, while the participants were standing with arms at the side, relaxed abdomen, and feet together [18]. Similarly, the hip circumference measurement was taken at the widest circumference of the proximal thigh, just under the fold of the gluteus, with feet separated slightly [18]. Whole body fat and fat free soft tissue mass were measured using dual-energy X-ray absorptiometry (DXA) (Hologic QDR 4500A, software version 11.2, Hologic Inc., (Bedford, Massachusetts, USA)).

Blood pressure

The Omron M6 (version HEM-7001-E, Omron, Kyoto, Japan) was used to record brachial blood pressure (BP). Three measurements were taken with the participant in the seated position with the cuff around the right upper arm, supported at the level of the heart [18]. The average of the last two BP measurements was recorded.

Biochemical analyses

Fasting blood samples were collected and centrifuged to obtain plasma and serum samples. Aliquot samples were stored at −70°C until assayed for lipid profile and glucose concentrations using an automated methodology (Randox Laboratories Ltd., County Antrim, UK). Insulin was measured (IMMULITE® 1000 Chemiluminescent Technology) and insulin resistance was quantified using the Homeostasis Model Assessment (HOMA) technique [19].

Metabolic disease risk factors

Metabolic disease risk factors were defined as systolic BP ≥130 mm Hg, diastolic BP ≥ 85 mm Hg, fasting blood glucose ≥5.6 $mmol.L^{-1}$, triglycerides (TG) ≥ 1.7 $mmol.L^{-1}$,

high density lipoprotein cholesterol (HDL-C) <1.3 mmol.L^{-1}, low density lipoprotein cholesterol (LDL-C) ≥ 3 mmol.L^{-1}, and total cholesterol (TC) ≥ 5 mmol.L^{-1} [20]. Central obesity was defined as a waist circumference ≥ 80 cm [20]. Metabolic syndrome was defined using the harmonised guidelines [20].

Physical activity questionnaire

The Global Physical Activity Questionnaire (GPAQ), developed for global physical activity surveillance, was completed via interview to obtain self-reported physical activity [21]. The hours of physical activity and metabolic-equivalent (MET) values per activity were multiplied together to give MET minutes per week. Moderate activity was allocated a MET value of four and vigorous physical activity a value of eight as outlined in the World Health Organisation (WHO) guidelines [22]. Total moderate-vigorous physical activity (MVPA) in minutes per week (mins/wk) were calculated from the accumulative occupation, travel-related and leisure time physical activity. Walking for travel was analysed individually as it was the most common form of physical activity noted in the study population. Minutes per week of work and leisure time physical activity were combined. Sitting time (mins/wk) was used as a proxy for sedentary behaviour.

The participants were also grouped according to the GPAQ criteria, into GPAQ active or GPAQ inactive categories [22]. GPAQ active was defined as taking part in: moderate physical activity for a total of 150 minutes per week (≥5 days per week); or vigorous physical activity for 60 minutes per week (≥3 days per week); or 600 metabolic minutes per week [≥5 days moderate-vigorous physical activity (MVPA)] [22]. Participants who did not meet these criteria were classified as inactive.

Socio-economic status

A questionnaire was used to assess household socio-economic status (SES) [23]. The questionnaire was based on the ownership of twelve household commodities: electricity, television, radio, motor vehicle, refrigerator, washing machine, telephone, video machine, microwave, analog television channel decoder (MNET), satellite television (DSTV), and mobile phone. The twelve household commodities were ranked in order of value and an overall SES score was then calculated using the ranks. The overall SES score ranged from 0 to 78.Television and motor vehicle ownership were stratified and analysed separately from the other household possessions as they are recognised as stimulators of sedentary behaviour [24,25].

Statistical methods

Statistica version 12 (StatSoft, Tulsa, OK, USA) was used to carry out the statistical analyses [26]. Prevalence levels for observed metabolic risk were determined using the harmonised guidelines [20]. Multiple imputation was used in dealing with missing body composition (fat mass, and fat free soft tissue mass) and metabolic outcome variables (fasting blood glucose, fasting insulin, HOMA, HDL, LDL, triglycerides, and total cholesterol). Multiple imputation with chained equations was then performed, using linear regression as the imputation model.

Dependent variables that were not normally distributed (systolic BP, fasting blood glucose, fasting insulin, HOMA, LDL, HDL, triglycerides) were log transformed to normality. Model assumptions of normality and constant variance were tested using Q-Q plots, and plots of residuals versus predicted values, respectively. Data are presented as mean ± SD if normally distributed; otherwise median [interquartile range (IQR)] is presented.

T-tests were used to compare body composition and metabolic outcomes between GPAQ active and inactive subjects, individuals who presented with the extremes of MVPA (above 90th and below 10th percentile) and physical activity between subjects who owned or did not own a motor vehicle or TV. A cluster variable was created using sitting time with total MVPA and then using ANOVA to compare metabolic and body composition measures between subjects in: highest tertiles for MVPA and sitting time (n = 129), lowest tertile for MVPA and sitting time (n = 111), highest tertile for MVPA and lowest tertile for sitting time (n = 77) and lowest tertile for MVPA and highest tertile for sitting time (n = 90). Differences between tertiles of walking for travel MVPA were explored using an ANOVA for body composition measures and metabolic outcomes, and Tukeys test, which takes into account multiple comparisons was used for the post-hoc analysis.

Multiple linear regression analyses were performed to determine if any of the physical activity variables were associated with the body composition and metabolic variables. The dependent variables were: total body fat mass, fat-free soft tissue mass, waist circumference, HOMA, fasting blood glucose, fasting insulin, total cholesterol, LDL, HDL and triglyceride, and systolic and diastolic blood pressures. The independent variables to include in the initial models were chosen based on scientific plausibility and for the models with anthropometric measures as the dependent variable these were: age, SES, fat mass (for the waist model only), sitting time, total MVPA, work MVPA, leisure MVPA and walking for travel. The multiple linear regression models that used metabolic measures as the dependent variables included the following independent variables: age, SES, total body fat mass, fat-free soft tissue mass, waist circumference, sitting time, total MVPA, work MVPA, leisure MVPA and walking for travel MVPA. Before performing multiple linear regression, simple univariate regressions were used to determine which of the independent variables listed above were associated with

the various dependent variables and these were included in the regression models. The final models were also checked for multicollinearity using the Variance Inflation factor (VIF), but no multicollinearity was noted (all VIFs < 3.0). The results of the regression models are reported as standardised β values to facilitate direct comparisons of the strengths of the associations. Significance was accepted at a level of $p < 0.05$.

Results

Subject characteristics, anthropometric measures and metabolic outcomes

The mean age of this cohort was 41.0 ± 7.84 years, with a high mean BMI (30.3 ± 6.73 $kg.m^{-2}$) and waist circumference (86.9 ± 13.2 cm) (Table 1). The percentage fat mass was also high (40.8 ± 7.38%). Fasting blood glucose levels were slightly raised, whilst insulin and HOMA levels were normal, and HDL levels were low (0.99 (IQR 0.78-2.00)), as were total cholesterol, LDL and triglyceride levels. Blood pressure values were within normal limits.

Physical activity

Physical activity data was obtained for 977 participants, 67% of whom were classified as physically active according to the Global Physical Activity Questionnaire (GPAQ) criteria. When using the WHO criteria, 75% of the participants met the minimum recommended guidelines for attainment of 150 minutes of moderate activity or 75 minutes of vigorous weekly activity [22]. Age was not significantly different between the physical activity groups. All domains of physical activity, except vigorous PA ($p = 0.64$), were significantly higher (all $p < 0.001$) in the GPAQ active group compared to the GPAQ inactive group (Figures 1 and 2). The median sitting time for the whole group was 3 hours a day, and was not significantly different between the activity groups (GPAQ active: 3 (IQR: 2–5) vs. GPAQ inactive: 3 (IQR: 1.5–4) hours per day).

Table 1 Subject characteristics, body composition and metabolic outcomes of middle aged black African women from the birth to twenty caregiver cohort

Characteristics	n	Mean ± SD or median (IQR)
Age (years)	964	41.0 ± 7.84
Body mass index ($kg.m^{-2}$)	977	30.3 ± 6.73
Waist circumference (cm)	964	86.9 ± 13.2
Hip circumference (cm)	964	112 ± 13.6
Waist-to-hip ratio	964	0.78 ± 0.08
Fat mass (kg)	655	28.9 ± 10.7
Fat free soft tissue mass (kg)	655	38.1 ± 5.96
Fat percentage (%)	655	40.8 ± 7.38
Fasting blood glucose ($mmol.L^{-1}$)	551	5.09 (4.59-5.80)
Fasting insulin ($pmol.L^{-1}$)	352	6.74 (4.46-9.14)
Homeostasis model insulin resistance	330	1.48 (0.96-2.11)
High density lipoprotein cholesterol ($mmol.L^{-1}$)	462	0.99 (0.78-2.04)
Low density lipoprotein cholesterol ($mmol.L^{-1}$)	462	1.31 (0.88-1.77)
Triglycerides ($mmol.L^{-1}$)	463	0.93 (0.71-1.67)
Total cholesterol ($mmol.L^{-1}$)	463	3.44 ± 1.77
Systolic blood pressure (mm Hg)	925	112 (103-126)
Diastolic blood pressure (mm Hg)	925	76.4 ± 12.5

Data presented as mean ± SD or median (interquartile range (IQR))

Association between physical activity and socio-economic status (SES)

Household SES score was inversely associated with time spent walking for travel ($r = -0.10$; $p < 0.01$), but was not associated with any other activity variable. Walking for travel was divided into tertiles for analysis, lowest tertile: n = 322, 0–90 minutes per week; middle tertile: n = 316, 90–210 minutes per week; and highest tertile: n = 339, ≥210 minutes per week. Participants in the lowest tertile for walking for travel had a significantly higher household SES score (6.48 ± 2.29) compared to women in the middle (6.08 ± 2.28, $p < 0.05$) and highest (5.81 ± 2.37, $p < 0.001$) tertiles.

Sedentary promoting assets and physical activity

Time spent walking for travel was significantly higher in the women who did not own a motor vehicle compared to those who did ($p < 0.01$), and significantly higher in the women who did not own a television compared to those who did ($p = 0.001$) (Table 2). Leisure time physical activity was significantly higher in the women who owned a motor vehicle compared to those who did not ($p < 0.01$). Women who owned a television reported less MVPA minutes/wk ($p < 0.01$) and total moderate PA ($p < 0.01$), than women who did not own a television (Table 2). Sitting time in the GPAQ active group, 1260 (IQR: 840–2100) minutes per week, did not differ significantly from the inactive group, 1260 (IQR: 630–1680) minutes per week.

Association between physical activity, and anthropometric measures and metabolic outcomes

The prevalence of overweight was 29.2% (95% CIs 26.3, 32.0), obesity 48.0% (95% CIs 44.9, 51.1), 66.2% of the women had a waist circumference ≥80 cm (95% CIs 63.2, 69.1), diabetes was observed in 29.0% (95% CIs 25.2, 32.8) of the cohort and the prevalence of metabolic syndrome in this cohort was 40.0% (95% CIs 35.5, 44.6). Table 3 shows that the absolute levels of the anthropometric and metabolic variables did not differ between the GPAQ active and inactive groups. In addition, there were no significant differences between any of the

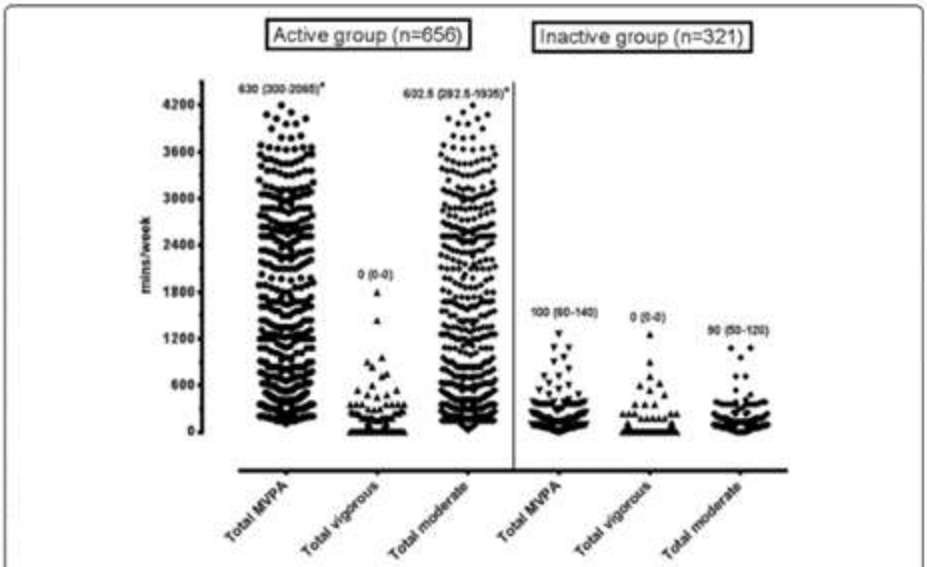

Figure 1 Comparative diagram of cumulative weekly physical activity for total MVPA, total vigorous and moderate physical activity between GPAQ active and GPAQ inactive groups. *p<0.05 when compared to matching physical activity domain.

anthropometric or metabolic variables when comparing women in the 90th (n = 99) and 10th (n = 101) percentiles for MVPA (data not shown). Sitting time was not different between those with metabolic syndrome and those without (data not shown). The exploratory cluster variable also failed to show any significant differences between cluster groups for BMI, waist circumference, body fat, systolic blood pressure, diastolic blood pressure, fasting blood glucose, HDL, LDL, total cholesterol, and triglycerides (data not shown).

The results of the multiple regression analyses using observed data can be viewed in Additional file 1. Using imputed data, multiple linear regression analysis demonstrated that sitting time was positively associated with HDL, triglycerides, and diastolic blood pressure (Table 4). The relationship sitting time and HDL was confounded by the interaction between triglycerides and HDL. Thus, when triglycerides were added to the HDL model, sitting time showed an inverse, non-significant relationship with HDL (beta coefficient (β): −2.13, p = 0.67). However, when triglycerides were removed from the HDL model, sitting time showed a positive association with HDL (β: 0.000002, p = 0.02). Inverse associations were observed between total MVPA and insulin, in addition to walking for travel and total cholesterol, whilst work MPVA was positively associated with fat free soft tissue mass. Age was found to be positively associated with body fat, waist circumference, fasting blood glucose, total cholesterol, LDL, triglycerides, systolic and diastolic blood pressure, whilst SES was positively associated with body fat mass and fat free soft tissue mass. Waist circumference was associated with fasting glucose, fasting insulin, LDL, total cholesterol, systolic and diastolic blood pressure (Table 4). No independent variables were found to correlate with HOMA levels following the regression analysis.

Discussion

The aim of this cross-sectional study was to determine the physical activity patterns of a cohort of middle-aged black women from Soweto, Johannesburg, who have previously been shown to be at high risk for metabolic disease. In this cohort of women in whom 67.0% were classified as physically active, the prevalence of obesity was 48.0%. This study is one of only a few to measure sedentary time in black South African women, and shows that despite a high level of physical activity and relatively low sitting time, metabolic disease risk is still high. Walking for travel significantly contributed to weekly physical activity, and was inversely associated with sedentary promoting assets including motor vehicle and television ownership.

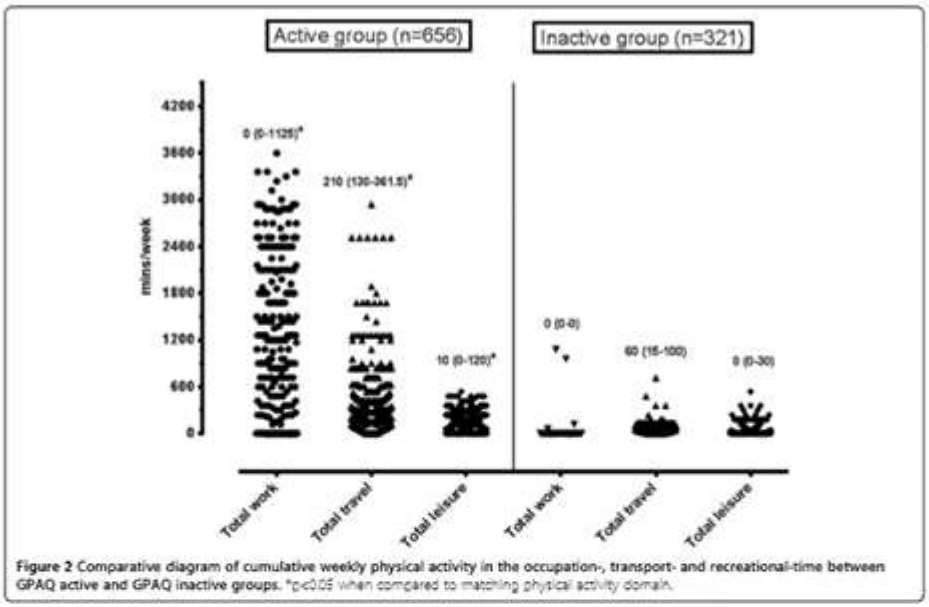

Figure 2 Comparative diagram of cumulative weekly physical activity in the occupation-, transport- and recreational-time between GPAQ active and GPAQ inactive groups. *p<0.05 when compared to matching physical activity domain.

The WHO defines being sufficiently active as accumulating a minimum of 150 minutes of moderate activity or 75 minutes of vigorous activity per week, however, this method does not take into account the various domains of physical activity [22]. Physical activity in developed countries typically encompasses a greater contribution from leisure time activity, whereas in developing countries work- and travel-related physical activity are the major contributors to daily energy expenditure [27]. In addition, physical inactivity is higher in more affluent countries than lower income countries [28]. However, longitudinal data from Brazil shows that there has been an increase in physical activity in the lower socioeconomic stratum over a 5 year period, suggesting a shift in physical activity patterns in low and middle income countries [29]. Using the GPAQ criteria which also takes into account the number of days per week of PA, the majority (67.0%) of women in this study were classified as physically active. This is comparable to the global level of physical activity in women (66.1%), in a study which also highlighted the lack of physical activity data from low and middle income African and Asian

Table 2 Physical activity domains of participants who do and do not own a motor vehicle or television (TV) ownership

Physical activity domains*	Motor vehicle and TV ownership					
	No motor vehicle (n = 601)	Motor vehicle (n = 211)	p-value	No TV (n = 738)	TV (n = 74)	p-value
Total moderate-vigorous physical activity	400 (150–1320)	315 (150–1260)	0.53	615 (240–2160)	360 (150–1260)	0.004
Total moderate physical activity	360 (140–1260)	300 (120–1200)	0.46	615 (210–2100)	315 (120–1230)	0.002
Total vigorous physical activity	0 (0–0)	0 (0–0)	0.16	0 (0–0)	0 (0–0)	0.41
Total work (moderate-vigorous physical activity)	0 (0–330)	0 (0–0)	0.39	0 (0–720)	0 (0–0)	0.06
Total walking for travel	150 (60–300)	120 (40–240)	0.009	210 (120–420)	140 (60–280)	0.001
Total leisure (moderate-vigorous physical activity)	0 (0–120)	30 (0–120)	0.004	0 (0–180)	0 (0–120)	0.39
Work-leisure (moderate-vigorous physical activity)	60 (0–960)	90 (0–760)	0.38	120 (0–1680)	60 (0–60)	0.16
Sitting time	1260 (840–2100)	1260 (840–1680)	0.26	1260 (840–1680)	1260 (840–2100)	0.94

*Units are minutes/week expressed as median (interquartile range).

Table 3 Comparison of metabolic risk outcomes and body composition between active and inactive black South African women based on multiple imputation

		GPAQ inactive		GPAQ active
Dependent variable	N	Mean (95% CI)	N	Mean (95% CI)
Fasting blood glucose (mmol.L^{-1})	309	5.13 (4.92, 5.33)	630	5.32 (5.10, 5.53)
Fasting insulin (pmol.L^{-1})	306	7.14 (6.31, 8.09)	625	6.79 (5.96, 7.71)
High density lipoprotein cholesterol (mmol.L^{-1})	306	1.27 (1.15, 1.40)	618	1.39 (1.23, 1.55)
Low density lipoprotein cholesterol (mmol.L^{-1})	306	1.26 (1.18, 1.35)	618	1.18 (1.12, 1.24)
Total cholesterol (mmol.L^{-1})	306	3.52 (3.3, 3.73)	618	3.30 (3.10, 3.50)
Triglycerides (mmol.L^{-1})	306	1.06 (0.99, 1.14)	618	1.10 (1.03,1.17)
Systolic blood pressure (mm Hg)	305	115 (112, 117)	620	114 (112, 117)
Diastolic blood pressure (mm Hg)	305	76 (74, 77)	620	77 (76, 78)
Fat mass (kg)	309	29.42 (28.21, 30.62)	635	29.01 (28.15, 29.87)
Fat free soft tissue mass (kg)	309	38.15 (37.47, 38.84)	635	38.34 (37.82, 38.85)
Waist circumference (cm)	316	86.06 (84.63, 87.49)	650	87.25(86.22, 88.28)
Body mass index (kg.m^{-2})	321	30.22 (29.48, 30.97)	656	30.30 (29.78, 30.81)

Data expressed as mean (95% CIs).
GPAQ: Global physical activity questionnaire.

countries [28]. However, the physical activity range in our study falls into the higher end of the range reported in other studies of black South African women (45.2-70.8%) [30,31]. In the study by Alberts et al. 45.2% (age-standardized) of rural women were classified as physically active at home using a lifestyle questionnaire [30], while the THUSA study found that 70.8% of rural women were physically active using a physical activity index which stratified the groups of physical activity in tertiles [31]. In comparison to these two South African studies, most of the women in the current study performed walking for travel (89.0%) whereas the percentage of subjects commuting by walking was lower in the THUSA study (27.4%) and the study by Alberts et al. (16%). However, it should be noted that the methods used in these studies for assessing physical activity were different to those used in the current study, making comparisons difficult.

This is one of the first studies to quantify daily sitting time (excluding sleep time), a proxy for sedentary time [32], in a large female African population. Evidence from studies suggest that sitting time is associated with both obesity and other metabolic diseases [33,34]. In our study sitting time was positively associated with triglycerides and diastolic blood pressure, which has also been observed in other studies [33,35]. In the current study 50.0% of the women reported sitting for 3 or more hours a day which is comparable to studies from India, China, and Brazil who report 3.5, 4, and 4.5 hours of sitting per day, respectively [36,37]. In our study, sitting time was not different between the active and inactive groups, suggesting that in this population, the amount of time spent sitting is independent of physical activity, and should be investigated as a distinct entity. This opinion is also shared by Bankoski et al. [38] and Chau et al. [39] who found that time spent sedentary was strongly related to the risk of metabolic disease independent of the time spent being physically active. Recent findings also show that patterns of sedentary behaviour varies by life domains such as television watching, personal computer use, and travel time [35].

Previous studies have identified motor vehicle ownership as a sedentary promoting asset [24,38]. Held et al. found that participants who owned a motor vehicle had an increased risk of myocardial infarction [38]. Similarly the review by Douglas et al. emphasises the integral role of car ownership in the increasing prevalence of physical inactivity and obesity in countries with low levels of active transport [24]. The current growth of the South African economy has resulted in motor vehicles becoming more affordable to a larger proportion of the population, as a result of which, vehicle ownership is increasing in urban settings such as Soweto [39]. In our study, sitting time was not different between the women who owned motor vehicles and those that did not; however the women who did not own a motor vehicle walked significantly more and performed significantly less leisure time physical activity than the women who did own a motor vehicle. This data suggests that the negative effect of car ownership on walking may be counteracted by an increased amount of leisure time physical activity. Leisure time physical activity has previously been shown to be associated with SES [40], so the role of SES and time spent in different sedentary life domains in determining physical activity patterns must also be considered [41].

The domains of physical activity in developing countries favour travel- and occupation-related physical activity,

Table 4 Multiple linear regression models for anthropometric and metabolic variables using imputed data

Dependent variable	N	Independent variables	Coefficients (95% CI)‡	Beta coefficient† (p-value)	Adjusted R^2 (p-value)
Fasting glucose	918	Age	0.001 (0.0004, 0.002)	0.10 (0.003)	0.02 (<0.001)
		Waist	0.0007 (0.0003, 0.001)	0.11 (0.001)	
Fasting insulin	916	Age	−0.002 (−0.005, 0.002)	−0.07 (0.04)	0.13 (<0.001)
		Waist	0.006 (0.004, 0.007)	0.35 (<0.001)	
		Total MVPA	−0.00002 (−0.00004, −0.000004)	−0.11(<0.001)	
High density lipoprotein cholesterol	914	Age	−0.001 (−0.003, 0.001)	−0.05 (0.16)	0.04 (<0.001)
		Waist	−0.003 (−0.004, −0.002)	−0.16 (<0.001)	
			0.00002 (0.000003, 0.00003)	0.08 (0.02)	
Low density lipoprotein cholesterol	917	Age	0.006 (0.002, 0.009)	0.28 (<0.001)	0.13 (<0.001)
		Waist	0.002 (0.0005, 0.004)	0.18 (<0.001)	
Total cholesterol	917	Age	0.04 (0.02, 0.07)	0.25 (<0.001)	0.09 (<0.001)
		Waist	0.009 (−0.009, 0.03)	0.09 (0.007)	
		Walking for travel	−0.0003 (−0.0009, 0.0002)	−0.08 (0.01)	
Triglycerides	921	Age	0.002 (−0.0002, 0.004)	0.08 (0.01)	0.02 (<0.001)
		Sitting time	0.00002 (0.000001, 0.00004)	0.12 (<0.001)	
Systolic blood pressure	923	Age	0.002 (0.002, 0.003)	0.24 (<0.001)	0.10 (<0.001)
		Waist	0.0009 (0.0006, 0.001)	0.17 (<0.001)	
Diastolic blood pressure	912	Age	0.21 (0.10, 0.30)	0.13 (<0.001)	0.08 (<0.001)
		Waist	0.20 (0.14, 0.26)	0.21 (<0.001)	
		Sitting time	0.001 (0.0002, 0.002)	0.06 (0.01)	
Body fat	925	Age	201.03 (112, 291)	0.15 (<0.001)	0.03 (<0.001)
		SES score	46.4 (9.82, 82.9)	0.08 (0.009)	
Fat free soft tissue mass	925	Age	1.11 (−46.4, 48.6)	0.002 (0.96)	0.01 (0.098)
		SES score	15.31 (−4.00, 34.62)	0.05 (0.12)	
		Work MVPA	0.46 (−0.001, 0.92)	0.06 (0.05)	
Waist circumference	925	Age	0.35 (0.25, 0.45)	0.21 (<0.001)	0.04 (<0.001)

‡Unstandardised model coefficients.
†Standardised model coefficients.
MVPA: moderate-vigorous physical activity.

which was confirmed in our findings [27]. Importantly, our study has provided data on the different domains of physical activity, which has only been investigated in a small number of African countries [42]. Our findings show that the majority of the women (89.5%) did not perform vigorous activity and that walking and occupational physical activities were the domains with the highest contribution (34% from walking and 56% from occupation related physical activity) to overall physical activity. A similar pattern of physical activity is evident in African countries such as Eritrea, Cameroon, Mali, and Mauritania, where active commuting contributes more than 50% to total daily physical activity [42]. Our study showed a positive association between activity in the work domain and fat free soft tissue mass, suggesting that physical activity may have a role in improving the overall health profile of this ageing population of women, despite them having a high body fat percentage. A recent study concurred with this finding, showing that exercise improved physical fitness and lean mass, but did not result in significant body fat or lipid profile changes following a 24 week intervention of strength and endurance training [43]. Studies have also shown that participation in regular physical activity is the best means of preventing the effects of sarcopenia on the physical functioning of ageing individuals [44,45]. Leisure time activity contributes the most to overall physical activity in developed countries [5]. A recent systematic review of the health benefits of walking as a means of transport confirms that there may be positive effects on hypertension and type 2 diabetes mellitus with longer duration walking [46].

Our findings showed that total MVPA was inversely associated with fasting insulin, indicating that being physically active has a role in enhancing insulin sensitivity. These results correspond with South African studies

which showed that physically active urbanised black women had lower serum insulin levels than inactive women [13], subsequently resulting in higher levels of insulin sensitivity [47]. These studies imply that meeting the recommended guidelines for physical activity may have long-lasting effects on insulin sensitivity.

This study used the GPAQ to measure physical activity. The GPAQ is cost-effective and has been validated for use in developing countries [27,48]. The reliability of the GPAQ has been tested in South Africa, with the results showed acceptable Kappa statistics, ranging from 0.66 (93.9% agreement) to 0.78 (89.3% agreement) across the domains of physical activity [21]. However, the major challenge of using this instrument is that it assesses self-reported physical activity which may lead to an overestimation of weekly activity [49]. Secondly, the GPAQ is not as sensitive as objective measurements of physical activity; however the GPAQ is still a useful tool for physical activity surveillance. Our South African data compares well with data from other African countries [42], such as Mozambique, Niger and Malawi who attain the majority of their activity from the work domain, ranging from 60-75% of total MVPA [42].

Another key drawback of this study is that it was cross sectional and therefore causality cannot be determined. We did not find an association between any of the physical activity domains and anthropometric measures or metabolic outcomes using a variety of statistical analyses. In an urban dwelling Cameroon population of women, lower amounts of MVPA was performed compared to ours (94 vs. 119 MVPA mins/per day) and a negative association was observed between physical activity and prevalence of metabolic syndrome [50]. Cook et al. found that more than half of the women (55.2%) in rural South Africa performed more than the recommended 10000 steps per day, and that ambulation reduced obesity risk in rural South Africans [15]. A reasonable assumption for the difference could be in the use of self-reported questionnaires in our study compared to objective measurement of physical activity used in the other studies. However another reason for the difference could be that the prevalence of obesity was also lower in the Cook study (27.1%) and similarly, the mean BMI of the women in the Cameroon study ranged from 23.7 in the highest quartile of physical activity to 28.3 in the lowest.

Conclusions

We have shown that despite the majority of urban dwelling black South African women being classified as physically active, there is still a high prevalence of obesity and metabolic disease in this population. As in other developing countries, the majority of time spent in physical activity is in the form of walking for travel, however the intensity of this activity is not known. Thus, we recommend that future research aims to determine whether the intensity of this walking modifies the level of cardiometabolic risk factors in this population. This study showed that sitting time was positively associated with serum triglyceride levels and diastolic blood pressure, whilst total MVPA was inversely associated with serum insulin levels. This data implies that future intervention studies for cardiometabolic disease prevention in urban African populations must aim to reduce daily sitting time and increase total MVPA.

Additional file

Additional file 1: Multiple regression models for anthropometric and metabolic variables using observed data.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

PJG, SDC, and NJC performed the statistical analysis and PJG wrote the paper. SAN and LM conceived and implemented the study. All authors read and commented on the paper. All authors approved the final version of the manuscript.

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APPENDIX 10: PUBLICATION–The role of lifestyle and psycho–social factors in predicting changes in body composition in black South African women

PLOS | ONE

RESEARCH ARTICLE

The Role of Lifestyle and Psycho-Social Factors in Predicting Changes in Body Composition in Black South African Women

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Abstract

Background

This study aimed to determine whether lifestyle and psycho-social factors determine changes in body composition over 10 years in a population of black African females with a high prevalence of obesity.

Materials and Methods

Data were collected from 430 women at baseline and 10-year follow-up. Dual energy x-ray absorptiometry-derived body fat mass and fat free soft tissue mass, and simple anthropometric measures were taken at both time points. Data on physical activity (PA), diet, smoking, and alcohol intake were collected at baseline. Body size dissatisfaction and body size discrepancy were determined at baseline using the feel minus ideal (FID) index and the perceived minus actual weight status discrepancy score (PAD), respectively.

Results

All body composition measurements increased over 10 years ($p<0.0005$). Two distinct groups of overweight/obese females were identified using PAD and FID: one that was content with their body size and one that wished to be leaner. Vigorous PA at baseline was inversely associated with absolute changes in all measures of adiposity. In subjects who underestimated their body size at baseline (74.0% of the study population) changes in total and peripheral levels of body fat were less than in subjects who correctly identified their body size. In the group that underestimated body size, more women wanted to be leaner than in the group who knew their body size (60.1% vs 47.5%, $p<0.05$).

Conclusions

Underestimation of body size is common and is associated with a lower gain in total body adiposity and a prevalent desire to lose weight.

Introduction

Recent research has predicted that the proportion of overweight and obese women in developing countries such as South Africa will continue to rise, whereas the reverse applies to developed countries [1]. The increasing prevalence of overweight and obesity in the South African (SA) population is associated with an excessive burden of several non-communicable diseases such as type 2 diabetes and hypertension [2, 3]. Black SA women are more affected by obesity than men [4], a pattern that is common across the African continent and other developing countries [1]. Furthermore, data from the recent SA National Health and Nutrition Examination Survey shows that obesity is more prevalent in urban than rural black SA women (42.2% compared to 31.8%) [4], as urbanised women live in an environment that favours unhealthy dietary patterns [5], reduced physical activity (PA) [6, 7], and greater sedentary time [8]. However no studies have investigated whether these factors predict changes in body composition in an African population over time.

Psychosocial factors associated with obesity and body size preference specific to black SA women have been reported in cross sectional studies [9, 10]. These factors include social desirability to be fatter and a general tolerance of obesity [11]. Black SA women and adolescent girls have been shown to underestimate actual body size, indicating a high level of body size discrepancy, and have a low level of body size dissatisfaction [12, 13]. Culturally a larger body size is preferred as it is perceived to signify beauty, wealth, happiness, higher socioeconomic status, and ability to produce children [14], while thinness is associated with weakness, poverty and illness such as tuberculosis and human immunodeficiency virus [15]. Furthermore, a recent study has shown that the body image silhouette chosen by urbanised black female adolescents for their ideal body silhouette represents a higher body mass index (BMI) than that chosen by white female adolescents. Within the same study, when asked what body silhouette they perceive their families would prefer them to have, black participants chose a silhouette with a BMI that was higher than that chosen by the white participants [16]. This study also showed that a higher percentage of black girls had an EAT-26 (Eating Attitudes Test) score >20 (indicating the possibility of developing eating disorders such as anorexia nervosa, bulimia nervosa, or preoccupation with food), and that a higher proportion of black adolescents girls, compared to white girls, had greater body size dissatisfaction, and were more likely to control what they ate. Another SA study similarly suggested that acculturation may be occurring in young black females, and that there could be a conflict between traditional beliefs and Western ideals around body size [17]. Therefore, the aim of this study was three-fold: (i) to describe the change in body composition over a 10 year period in a cohort of urban black SA women; (ii) to determine whether baseline measurements of body size dissatisfaction and body size discrepancy are associated with baseline body composition measures, and correlate with changes in body composition variables over 10-years of follow-up, and (iii) to determine whether baseline lifestyle factors including diet and physical activity are associated with changes in body composition.

Materials and Methods

Study population

This longitudinal study included black SA urban-dwelling women from Soweto, Johannesburg. These women were caregivers of participants from the Birth to Twenty (Bt20) cohort, a study which started in 1990 with a sample of 3,273 subjects to examine the health and development of children [18, 19]. The majority (78.8%) of the sample were biological mothers of the Bt20 cohort, with the remainder being related to the child in some way. Baseline data were collected

on all caregivers who were black African and > 18 years of age in 2002/3 (n = 1,251). Follow up data collection was completed 10 years later (2012/13) on 702 women, 428 of whom had anthropometric (weight and height) data at both time points. The Human Research Ethics Committee at the University of the Witwatersrand granted ethical clearance to perform this study and the participants provided written informed consent (M110627).

Body composition

An electronic weighing scale (Dismedinc., Anjou, Canada) was used to measure total body weight (nearest 0.1 kg) and a wall mounted stadiometer (Holtain Ltd., Crosswell, UK) to measure standing height (nearest 0.1 cm) of the participants while dressed in minimal clothing and barefoot. Body mass index (BMI; $kg.m^{-2}$) was calculated. Waist and hip circumferences were measured using an inelastic, flexible tape measure. Waist circumference (WC) was measured at the narrowest region of the torso whilst the participant stood erect with feet close together. Hip circumference (HC) was measured around the widest part of the buttocks just below the gluteal fold [20]. The measurements were performed by trained research assistants, all of whom had a coefficient of variation (CV) <1% for body weight and standing height measurements, and <2% for waist and hip circumference measurements.

Dual-energy X-ray (DXA) absorptiometry (Hologic QDR 4500A, software version 11.2, Hologic Inc., Bedford, Massachusetts, USA) was used to measure total body fat mass, central (trunk) and peripheral (arms and legs) adiposity, and fat free soft tissue mass (FFSTM) (CVs for DXA parameters were <2% for total fat mass, and 1% for fat-free soft tissue mass).

Body size dissatisfaction and body size discrepancy

At baseline, drawings of nine female body silhouettes (adapted from Stunkard et al. [21]) ranging from 'very thin' (numbered as 1) to 'very heavy' (numbered as 9) were shown to participants and used to evaluate body size dissatisfaction and body size discrepancy. Body size discrepancy was assessed by calculating a discrepancy score between perceived and actual weight status (PAD) using a method adapted from Mchiza et al. and Zaccagni et al. [9, 22]. The participant chose a silhouette that they considered best represented their current weight. These were coded as follows: 1 = silhouettes 1 and 2 [underweight]; 2 = silhouettes 3–5 [normal weight]; 3 = silhouettes 6 and 7 [overweight]; 4 = silhouettes 8 and 9 [obese]). The PAD score was then calculated by subtracting the actual BMI status (coded using measured BMI as: 1 = underweight [$<18.5\ kg.m^{-2}$], 2 = normal weight [18.5–24.9 $kg.m^{-2}$], 3 = overweight [25.0–29.9 $kg.m^{-2}$], 4 = obese [$\geq 30.0\ kg.m^{-2}$]) from the code for the perceived weight status silhouettes. Negative PAD scores represent underestimation of weight status, positive scores represent overestimation of weight status, and zero scores represent participants who had an accurate perception of their weight status.

Body size dissatisfaction was measured by asking the participant to choose the silhouette that best portrayed how they wanted to look (known as the 'ideal' body shape). This was then subtracted from the 'feel' score (the silhouette that portrays what they perceive themselves to look like) to calculate the feel minus ideal (FID) score. Positive scores represent a desire to be leaner, a zero score represents contentment with body size, and negative scores indicate a desire to be fatter [10, 23]. The body size dissatisfaction and body size discrepancy scores were used to categorise the participants into negative, zero and positive groups of PAD and FID.

Dietary behaviour, alcohol consumption and tobacco use

High fat consumption was measured at baseline using an adapted food frequency questionnaire from a previous SA study investigating factors associated with overweight and obesity

[24]. The questionnaire determined consumption frequency of high fat foods in the past week including fatty cuts of red meat, chicken with skin, full cream milk, processed meats, crisps, and fried food items, e.g. fried eggs, fish and French fries, consumed on a regular basis (≥1 day per week). Alcohol intake was categorised as low (<1 drink/day), moderate (1–3 drinks/day), or high (>3 drinks/day). Current smoking status was also determined by questionnaire. All participants were asked if they had attempted to lose weight in the last 24 months by reducing their food intake, taking diet shakes/drinks, and/or joining organisations which focus on structured weight reduction programmes.

Physical activity questionnaire

The Global Physical Activity Questionnaire (GPAQ), developed for global physical activity surveillance, was completed via interview to obtain self-reported physical activity at baseline [25]. Total moderate-vigorous physical activity (MVPA) in minutes per week (mins/wk), was calculated from the sum of occupation, travel-related (walking) and leisure time MVPA. Examples of moderate (e.g. mopping the floor at home) and vigorous (e.g. carrying a load on the head while walking uphill) intensity activities in these various domains were explained to each of the participants. Walking for travel was analysed individually as it was the most common form of physical activity observed in this study population. Sitting time (measured in mins/wk) was used as a proxy for sedentary behaviour.

Socio-economic status

Asset ownership was used as a proxy measure for household socio-economic status (SES) at baseline [26]. The questionnaire was based on the ownership of twelve household commodities: electricity, television, radio, motor vehicle, refrigerator, washing machine, telephone, video machine, microwave, analogue television channel decoder for subscription television, satellite television, and mobile phone. The twelve household commodities were ranked in order of value and an overall SES score was then calculated using the ranks. The overall SES score ranged from 0 to 78. Level of education was also used as a measure of SES, and was categorised as no education (coded as '0'), completed primary school but did not attend high school (coded as '1'), attended high school but did not graduate (coded as '2') and completed high school (coded as '3').

Statistical methods

Analyses were performed on the women for whom we had body composition and weight and height data at baseline and 10-year follow-up (N = 428). The Statistica software package was used for all statistical analyses (version 12, StatSoft, Tulsa, USA) [27]. Data that were not normally distributed (total MVPA, total walking for travel, vigorous physical activity, moderate physical activity, and total sitting time per week) were log transformed to normality. Continuous, normally distributed variables are presented as mean ± SD whilst data that was not normally distributed is presented as median (interquartile range [IQR]). Differences between baseline and 10 year data were assessed by Student's paired t-test or Chi-square test. Variables were compared between the 3 FID, and between the 3 PAD groups, using ANOVA and followed by the Tukey *post hoc* test only in cases when the ANOVA was significant ($p<0.05$).
A cluster variable was created using physical activity and consumption of fatty foods with ANOVA used to compare body composition across the following groups: physically inactive and consume high fat foods (n = 100), physically inactive and consume low fat foods (n = 19), physically active and consume high fat foods (n = 240), physically active and consume low fat foods (n = 33).

Multiple linear regression analyses were conducted to determine if baseline (predictor) variables were associated with absolute changes in the body composition (outcome) variables (FFSTM, waist circumference, BMI, central adiposity, peripheral adiposity, and total body fat mass) 10 years later after adjusting for potential confounding variables, i.e. age, SES score, education, and the respective baseline body composition variables. Results of the multiple linear regression models are presented as standardised β values to enable direct comparison of the strengths of the associations. Prior to performing multiple regression analysis, simple bivariate analyses were performed to determine which of the following baseline (predictor) measures [total vigorous physical activity, total walking for travel, alcohol use, cluster variable for physical activity status and consumption of fatty foods, smoking status, weight loss practices, FID score and PAD score] were associated with the various dependent variables, and those with $p<0.05$ were included in the multivariate regression models along with the four possible confounding variables described above. Only the independent variables that had significant ($p<0.05$) β values are reported in the results section. Collinearity between independent variables was assessed using the Variance Inflation Factor (VIF), and no collinearity was observed (all VIFs<2.0). Dummy variables were generated for the following variables: FID and PAD scores, the cluster variable for physical activity and consumption of fatty foods, education, smoking status, and alcohol consumption. The reference groups for each of these variables were as follows: zero FID, zero PAD, physically active and low fat consumption, no education, non-smokers, and people who do not consume alcohol. Significance was accepted at an alpha level of $p\leq0.05$.

Results

Characteristics of the study cohort

Mean age at baseline was 41.1 ± 5.35 years and at follow-up age was 49.3± 5.33 years. Within the study cohort 49.5% of participants had completed high school. Complete DXA data was not available at both time points for all subjects due to the fact that not all study subjects were able to perform DXA scans at the baseline visit on weekdays due to work commitments and we could only accommodate a small number of subjects for data collection on weekends. Women for whom DXA data was available at both time points (n = 264) were slightly older, but showed no differences for any of the other measured variables when compared to women without (n = 164) DXA data (S1 Table). There was a significant increase in all body composition measures between baseline and follow up (all $p<0.001$), with a mean weight gain for the whole sample of 5.17 ± 8.86 kg (Table 1). The prevalence of a high waist circumference (≥80cm) and obesity (BMI ≥30kg.m^{-2}) increased significantly between baseline and follow-up (both $p<0.001$).

Body size perception and body size discrepancy

At baseline, 10.5% of subjects wanted to be fatter (negative FID score), 57.4% wanted to be leaner (positive FID score), and 32.1% were content with their body image (zero FID score; Table 2). The proportion of women in each of these groups did not change significantly at follow-up, i.e. 9.1% subjects wanted to be fatter, 53.7% wanted to be leaner, and 37.2% were content with their body size. At baseline, women who wanted to be leaner had a significantly higher BMI, waist and hip circumferences, central and peripheral adiposity, and total fat and fat free soft tissue mass, than those with a negative or zero FID score ($p<0.0005$ for all comparisons). Similar differences were observed at follow up (S2 and S3 Tables). There were no differences between the FID groups for absolute change in the any of the body composition

Table 1. Body composition characteristics at baseline and at 10-year follow-up

Variable	N*	Baseline	Follow-up	Percentage change
Weight (kg)	428	77.4 ± 17.3	82.6 ± 18.9*	7.13 ± 12.1
Body mass index (kg.m^{-2})	428	30.8 ± 6.70	33.1 ± 7.36*	7.98 ± 11.9
Waist circumference (cm)	416	97.7 ± 13.2	98.5 ± 14.7*	12.8 ± 11.4
Hip circumference (cm)	413	114 ± 13.7	119 ± 15.2*	4.09 ± 7.44
Waist-to-hip ratio	413	0.77 ± 0.08	0.83 ± 0.08*	8.65 ± 9.96
Fat mass (kg)	264	29.8 ± 10.2	32.9 ± 10.6*	13.6 ± 23.75
Fat free soft tissue mass (kg)	264	38.5 ± 5.86	45.0 ± 7.29*	17.2 ± 7.99
Central adiposity (kg)	261	13.4 ± 5.28	14.4 ± 5.33*	11.6 ± 28.7
Peripheral adiposity (kg)	261	16.4 ± 5.49	17.7 ± 5.84*	9.8 ± 20.5
Obesity (BMI>30 kg.m^{-2})	428	50.9 (46.2, 55.7)	65.8 (61.4, 70.4)*	29.3*
Waist (>80cm)	416	70.6 (66.2, 75.0)	89.9 (87.0, 92.8)*	27.3*

Data presented as mean ± SD for continuous data and % (95% CIs) for categorical data; *N at baseline and at 10-year follow-up

*p<0.001 versus baseline values

*Formula for percent change in prevalence: (follow-up prevalence–baseline prevalence)/baseline prevalence.

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measures even when this data was expressed as percentage change from the baseline, and when FID negative and zero groups were combined and compared with the FID positive group.

With regard to body size discrepancy at baseline, 74% of the subjects underestimated their actual body size (negative PAD score), 2% overestimated actual body weight (positive PAD score), and 24% correctly perceived their actual body weight (zero PAD score, Table 3). At follow up, the proportion of women in each of the PAD groups were similar to baseline, i.e. 73.5%, 0.70%, and 25.8% respectively. Women who underestimated actual body weight status had a significantly higher BMI, waist and hip circumferences, and total fat and fat free soft tissue mass, than those who overestimated or correctly perceived their actual body weight ($p<0.0005$ for all comparisons). Women who correctly perceived actual body weight had a significantly greater increase in fat mass than the women who underestimated body weight.

There were 316 participants who underestimated their body size. These subjects had a high BMI (32.6 ± 5.74; see Table 3) and 60.1% of them wished to be leaner i.e. had a positive FID score, 8.20% wanted to be fatter, and 31.7% were content with their body size. The women who underestimated but were content with their body size were older (42.7 ± 5.28 vs 40.4 ± 5.16 years; $p<0.05$) and less obese (30.3 ± 4.01 vs 34.5 ± 5.78; $p<0.0005$) than those women who wanted to be thinner, and less of them completed high school compared to the latter group (46.0% vs 56.3%; $p = 0.06$). There were 103 participants who accurately perceived their body size, of whom 17.5% wanted to be fatter, 35% were content with their body size and 47.5% wanted to be leaner (for the latter value (47.5%), $p<0.05$ vs those subjects who underestimated body size and wanted to be lean (60.1%)).

Lifestyle factors

The median (IQR) sitting time for all participants at baseline was 1260 (840–1890) minutes per week, and was significantly different ($p<0.05$) between the subjects who wanted to be fatter (1680 (840–2940) minutes per week) compared to the subjects who were content with their body size (1260 (840–1680) minutes per week) and the subjects who expressed a desire to be thinner (1260 (840–1680) minutes per week). For all participants the median time spent in walking for travel was 150 (60–300) minutes per week, for work MVPA was 0 (0–0) minutes per week, and for leisure MVPA was 0 (0–120) minutes per week. Total median MVPA was

Table 2. Comparison across baseline FID groups of baseline body composition measures and absolute change in body composition variables over 10-year follow-up.

Variable	Subjects who wanted to be fatter	Subjects who were content with their body size	Subjects who wanted to be leaner
Proportion in each FID group (%)[b]	10.5% (45)	32.1% (138)	57.4% (247)
Age (years)	42.2 ± 5.84 (45)	42.1 ± 5.49 (138)	40.3 ± 5.05 (247)
BMI (kg.m^{-2})[b]	25.1 ± 4.16 (44)	28.4 ± 4.91 (137)[†]	33.2 ± 6.85 (247)[***] [***]
Absolute change in BMI (kg.m^{-2})	1.46 ± 2.99 (44)	2.60 ± 3.54 (137)	2.31 ± 3.54 (247)
Waist circumference (cm) [b]	77.2 ± 8.21 (45)	83.4 ± 10.4 (136)	91.8 ± 13.6 (243) [***] [***]
Absolute change in waist circumference (cm)	10.5 ± 8.11 (43)	11.1 ± 8.91 (134)	10.7 ± 10.0 (238)
Hip circumference (cm) [b]	102 ± 9.28 (45)	110 ± 10.8 (136)[†]	119 ± 13.8 (242) [***] [***]
Absolute change in hip circumference (cm)	2.98 ± 6.08 (43)	4.58 ± 7.42 (133)	4.69 ± 9.86 (237)
Fat mass (kg) [b]	20.2 ± 6.35 (33)	28.0 ± 9.29 (87)[†]	33.4 ± 10.4 (157) [***] [*]
Absolute change in fat mass (kg)	4.02 ± 6.04 (32)	3.53 ± 6.10 (84)	2.72 ± 5.89 (148)
Fat free soft mass (kg) [b]	35.9 ± 5.10 (33)	37.1 ± 5.18 (87)	40.3 ± 6.38 (157) [***] [***]
Absolute change in fat free soft mass (kg)	5.78 ± 2.99 (32)	6.49 ± 2.88 (84)	6.80 ± 3.28 (148)
Central adiposity (kg) [b]	8.68 ± 3.34 (32)	12.3 ± 4.68 (86)	15.2 ± 5.29 (155) [***] [*]
Absolute change in central adiposity (kg)	1.56 ± 2.88 (30)	1.15 ± 3.20 (84)	0.79 ± 3.10 (147)
Peripheral adiposity (kg) [b]	11.5 ± 3.56 (32)	15.6 ± 5.05 (86)	18.1 ± 5.82 (156) [***] [*]
Absolute change in peripheral adiposity (kg)	1.64 ± 2.67 (30)	1.48 ± 3.06 (84)	1.29 ± 3.46 (148)

Data presented as mean ± SD (n)

[†]P<0.05

[***]P<0.0005 versus subjects who wanted to be fatter

[*]P<0.05

[***]P<0.0005 versus subjects who were content with body shape

[b] baseline values.

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350 (150–1240) minutes per week, total vigorous physical activity and total moderate physical activity were 0 (0–0) and 315 (150–1240) minutes per week, respectively. None of these physical activity variables measured at baseline were associated with body size discrepancy or body size dissatisfaction, and were also not significantly different between the PAD or FID groups.

The majority of participants (88.2%) reported consuming butter or margarine on bread, 55.9% reported eating chicken with skin, 48.6% ate processed meat, 33.7% ate red fatty meats, and 49.8% drank full cream milk on a regular basis (>1 time per week). A significantly higher amount of women who wanted to be leaner consumed fatty red meat compared to those women who wanted to be fatter (44.4% vs. 13.5%, $p<0.05$). The majority (97%) of the participants did not smoke, and 16.7% consumed alcohol on a regular basis (≥1 time per day), whilst 25.7% had participated in some form of weight loss strategy in the past 24 months. A significantly higher number of women who wanted to be leaner participated in some form of weight programme compared to those women who indicated a desire to be fatter (84% vs. 13%, $p<0.0001$). No significant differences were noted between the groups defined using the cluster variable (physical activity and fatty food intake) for changes in body composition (as determined by ANOVA). This cluster variable also did not contribute significantly to the multiple regression models shown in Table 4.

Table 3. Comparison across baseline PAD groups of baseline body composition measures and absolute change in body composition variables over 10-year follow-up.

Variable	Subjects who underestimated actual body size	Subjects who accurately perceived actual body size	Subjects who overestimated actual body size
Proportion in each PAD group (%)[b]	74% (316)	24% (103)	2% (9)
Age (years)	41.3 ± 5.41 (316)	40.3 ± 5.18 (103)	42.4 ± 4.64 (9)
BMI (kg.m^{-2})[b]	32.6 ± 5.74 (316)	26.2 ± 6.89 (103)	21.5 ± 2.39 (9) *** ***
Absolute change in BMI (kg.m^{-2})	2.17 ± 3.60 (316)	2.80 ± 3.66 (103)	1.81 ± 2.47 (9)
Waist circumference (cm)[b]	91.0 ± 11.9 (312)	78.6 ± 12.3 (101)	72.0 ± 6.93 (9) *** *
Absolute change in waist circumference (cm)	10.4 ± 9.73 (307)	12.3 ± 8.79 (97)	10.6 ± 6.97 (9)
Hip circumference (cm)[b]	117 ± 12.2 (312)	106 ± 13.8 (100)	94.4 ± 7.81 (9) *** ***
Absolute change in hip circumference (cm)	4.17 ± 9.14 (306)	5.54 ± 7.88 (96)	4.73 ± 5.98 (9)
Fat mass (kg)[b]	33.3 ± 9.38 (209)	21.2 ± 7.98 (60)	15.2 ± 5.03 (7) *** ***
Absolute change in fat mass (kg)	2.57 ± 6.92 (198)	5.04 ± 5.99 (59) ***	3.24 ± 3.88 (6)
Fat free soft mass (kg)[b]	40.3 ± 5.66 (209)	34.8 ± 4.99 (60)	28.4 ± 2.59 (7) *** ***
Absolute change in fat free soft mass (kg)	6.89 ± 3.13 (198)	5.88 ± 2.87 (59)	3.86 ± 2.44 (6)
Central adiposity (kg)[b]	15.6 ± 4.67 (206)	8.79 ± 4.02 (59)	6.33 ± 2.35 (7) *** ***
Absolute change in central adiposity (kg)	0.73 ± 3.10 (196)	1.85 ± 3.11 (58)	1.20 ± 2.28 (6) ***
Peripheral adiposity (kg)[b]	18.1 ± 5.26 (206)	12.3 ± 4.60 (60)	8.86 ± 3.21 (7)
Absolute change in peripheral adiposity (kg)	0.99 ± 2.98 (196)*	2.74 ± 3.93 (59)	1.25 ± 1.71 (6)

Data presented as mean ± SD (n)

*P<0.05

***P<0.0005 versus subjects who underestimated actual body size

*P<0.05

***P<0.0005 versus subjects who accurately perceived actual body size

[b]baseline values.

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Multivariate regression

The multivariate regression models showing the contribution of various baseline factors to change in body composition are presented in Table 4, with age, SES, education and the respective baseline body composition variables included in each of the 6 models. Total vigorous physical activity and high alcohol consumption (≥3 drinks/day) were each inversely associated with absolute change in waist circumference (model 1). In the model for absolute change in BMI (model 2), total vigorous physical activity was the only significant independent variable. Smoking and age were inversely associated with change in FFSTM, while baseline FFSTM was positively associated (model 3). Although the prevalence of smoking was low (3%) an effect was seen on change in FFSTM and this is due to a strong effect of smoking as shown by the difference in change in FFSTM between smokers (n = 13) and non-smokers (n = 382) (3.03 ± 2.81 vs 6.69 ± 3.13, p = 0.003). Model 4 showed that total vigorous physical activity and baseline total body fat were both inversely associated with an absolute change in total body fat, which was lower in those who underestimated body size when compared to those who accurately assessed body size. Total vigorous physical activity and baseline central adiposity were both inversely associated with change in central adiposity (model 5). Total vigorous physical

Table 4. Multiple linear regression analyses displaying the major predictors of change in body composition in black African women from Soweto.

Model number	Dependent variables	N	Independent variables	Beta coefficients (P-value)
1	Absolute change in waist circumference	382	Alcohol intake at baseline (>3 drinks/day):	-0.15 (0.003)
			Total vigorous PA (baseline):	-0.15 (0.002)
			Waist circumference (baseline):	-0.17 (0.001)
2	Absolute change in body mass index	430	Total vigorous PA (baseline):	-0.11 (0.02)
3	Absolute change in fat free soft tissue mass	241	Active smoker at baseline:	-0.14 (0.02)
			Age (baseline):	-0.14 (0.03)
			Fat free soft tissue mass (baseline):	0.21 (0.003)
4	Absolute change in total body fat	264	Subjects who underestimated actual body size (baseline):	-0.16 (0.01)
			Total body fat (baseline):	-0.22 (0.002)
			Total vigorous PA (baseline):	-0.12 (0.04)
5	Absolute change in central adiposity	260	Central adiposity (baseline):	-0.24 (0.001)
			Total vigorous PA (baseline):	-0.15 (0.01)
6	Absolute change in peripheral adiposity	261	Subjects who underestimated actual body size (baseline):	-0.15 (0.03)
			Total vigorous PA (baseline):	-0.13 (0.04)

Data presented as standardised beta coefficient (p-value).

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activity and an underestimation of body size were both negatively associated with absolute change in peripheral adiposity (model 6).

Discussion

In this cohort of ageing black South African women we observed significant weight gain over a 10 year period, with an obesity prevalence of 65.8% at follow up, and with nearly 90% of the participants having a waist circumference ≥80cm. The most significant contributors to less change in the various body composition measures were the underestimation of body size at baseline, time spent doing vigorous physical activity, and alcohol consumption.

This study is the first to determine the contribution of body image to long-term body composition change in black SA women. Our study demonstrates that the majority (57.4%) of the women wished to be leaner, and that these women had higher baseline BMI, total body fat and fat-free mass, central and peripheral adiposity, waist and hip circumference values, than the women who wanted to be fatter and those who were happy with their body size. In contrast, previous cross-sectional studies have shown that African women have a general acceptance of overweight and obesity [11], with a larger body size traditionally being viewed as a symbol of beauty, wealth, happiness, and optimal fertility in African cultures [11, 14, 28], whereas leanness was associated with sickness and lower socioeconomic status [15]. Our data therefore suggests that within our cohort of adults the acceptance of female obesity within African traditions exists side-by-side with a more western ideal of a lower body weight. Within adolescent black females the situation is similar, with the study of Gitau et al. [16] showing that although black adolescent females are more comfortable with a body size that is higher than that selected by white adolescents females, the black females were more likely to have a predisposition toward eating disorders than their white counterparts. This again suggests a clash between the traditional African view of overweight/obesity as being the ideal female body state and the modern Western tradition of leanness as the ideal female body state [17].

This is the first study to have measured whether the discrepancy between actual and perceived weight status in SA women predicts future weight gain. The majority (74%) of women at baseline underestimated their weight and had significantly higher measures of all body composition parameters at baseline, when compared to the other groups. However these women had less absolute change in central and peripheral adiposity at follow up when compared to those subjects who had accurately estimated their body size. This may be related to the fact that a higher proportion of this group wanted to be leaner when compared to the subjects who accurately identified their body size. This may be advantageous for future obesity intervention programs. Other SA studies have also shown that black African females tend to underestimate their actual body size [12, 13]. However, 31.7% of the women who underestimated their body size were content with their weight status, even though their mean BMI was high at 30.3 ± 4.01. Fewer of these women had completed high school and were older than those women who wished to be leaner. These data suggest that within our study population there are two distinct groups of overweight/obese women who differ in terms of age, education and the desire to lose weight. These findings may be important when introducing obesity intervention programs into this population, with different approaches required for each group of women.

This is the first longitudinal study on the effect of physical activity on weight change in black African females. Our results showed that baseline total vigorous physical activity was inversely associated with change in BMI, waist circumference, total body fat, and central and peripheral adiposity. These results are comparable to those from a study conducted in middle-aged obese and sedentary American women which showed that higher intensity physical activity was more effective in reducing both intra-abdominal and subcutaneous fat than lower intensity physical activity [29]. Further, it has been observed that exchanging 1 hour of sitting time with light physical activity can significantly decrease both visceral and subcutaneous adipose tissue [30]. In our study, sitting time was significantly lower in those women who wanted to be leaner compared to those women who wanted to be fatter, but body size dissatisfaction and body size discrepancy were not associated with differences in the level of physical activity. This data suggests that body size dissatisfaction or discrepancy may not have an impact on physical activity behaviour in this population, which is contrary to one previous study which has shown that physical activity is perceived to be associated with thinness [13], and that body size dissatisfaction may modulate sedentary behaviour. Moreover, participating in vigorous physical activity provides additional advantages to health such as improved skeletal health and reduced risk of cardiovascular diseases [31]. However, only 10% of the women in our study participated in vigorous intensity physical activity, which is similar to the data for women from other developing countries [6, 32]. These data suggest that efforts to combat obesity in this population should include high intensity physical activity programmes.

Findings in other studies of alcohol consumption and body weight have shown that more frequent drinking is associated with leanness [33, 34], while binge drinking is associated with central obesity [35]. In comparison, our findings show that higher alcohol consumption was inversely associated with change in waist circumference. This finding is consistent with a large Danish longitudinal study which showed that the level of alcohol intake was inversely associated with change in waist circumference in women [36]. The authors attribute this result to a thermogenic effect, i.e. the action of alcohol dehydrogenase and the microsomal ethanol-oxidising system increasing thermogenesis in frequent alcohol drinkers. Our analysis also shows that smoking has an inverse association with change in FFSTM, implying that women in our cohort who smoke gain less muscle mass over time. Our findings also show that age was negatively associated with change in FFSTM, reinforcing the well documented loss of muscle mass with ageing [37]. The main result of premature sarcopenia would be a loss of functional capacity, particularly for activities of daily life that require muscle strength. Nicotine acts as an

appetite suppressant and increases energy expenditure, which may explain the reason for smokers tending to have lower body weight than non-smokers, and why smoking cessation is followed by an increase in fat mass [38]. As active smoking was only observed in 3% of the cohort in our study, and because this is a cross sectional analysis causality should be inferred with caution. With regards to dietary behavior, we showed that many of the women in our study ate foods high in fat. In spite of this, the consumption of these foods did not influence long term weight gain. This is consistent with a large American study, which showed a weak non-significant correlation between weight change and whole fat dairy foods, but a strong negative correlation with nuts, vegetables and fruits [39].

In South Africa [12, 40, 41] and other sub-Saharan African countries [42, 43], SES has been shown to be positively associated with obesity in cross sectional studies, as has level of education [12, 40–43]. However, the findings from our study show that baseline measures of education or SES did not affect change in body composition. The reason for this finding is not known however one possible explanation may be the low variation in education and SES levels within this cohort. Socioeconomic status and alcohol intake were only measured at baseline in our study and therefore the effect of changes in these variables could not be assessed. However it is unlikely that SES would change sufficiently over the study period to modulate any of the outcome variables. It is possible that alterations in alcohol consumption over the 10 year period may have effects on body composition changes, but it must be noted that the prevalence of alcohol usage in this cohort was low.

This longitudinal study has a number of limitations including the use of self-reported physical activity and sedentary behaviour, derived from the GPAQ instrument. This questionnaire has the potential to overestimate both physical activity and sitting time. However, GPAQ has been shown to be reliable for use in African populations [25], and our findings are comparable with physical activity data from other African countries [32], and adds to a small body of evidence from low-and-middle-income countries. Secondly, the self-reported dietary questionnaire only considered high fat foods which have previously been associated with obesity in South Africa [24]. We observed that consumption of these foods were common amongst the participants in this study. Future studies in this population should also consider the impact of other foods which were not considered in the present investigation e.g. high carbohydrate foods and sugar sweetened drinks. Thirdly, it would have been ideal to have more regular follow-up visits of this cohort, but due to infrastructural constraints this was not possible. However, the 10-year period allowed for greater changes of the anthropometric variables than would be observed over a shorter time period thus allowing us to more easily isolate predictor variables. A further limitation was that DXA data was not available for the full cohort. However, when comparing the women for who complete DXA data was available to those for who it was not, there were no differences in any of the measured variables with the exception of age, which was slightly lower in the latter group. This suggests minimal selection bias for the group with DXA data available at both time points. Lastly, an assumption has been made that the desire for, or the acceptance of, a higher body size is the consequence of a traditional African belief in the positive aspects of obesity. Questions were not asked of the study participants to validate this assumption, although previous reports have described such beliefs [11, 14]. Comparison with a European population would have allowed us to determine whether this acceptance of a high body size was more prevalent in an African population, although other studies have shown this to be the case [9, 16].

Conclusions

The findings of this longitudinal study demonstrate that in our cohort of black urbanised South African women time spent in vigorous physical activity was associated with smaller increases in body weight and adiposity. However, only a small percentage of subjects participated in vigorous PA. In addition, the majority of participants who were overweight or obese underestimated their body size and this was related to a smaller gain in body adiposity and a more prevalent desire to lose weight than in subjects who accurately identified their body size. Additionally, in agreement with previous studies that have reported that black South African women are more accepting of being obese [11, 14, 28], our study highlighted the existence of a further group of overweight/obese women who were content with their body size. Thus, the presence of two distinct groups of overweight/obese women within our study population, one wishing to be thinner and the other content with their body size, may reflect a clash of traditions with the former group appearing to be more closely aligned with Western values focussing on leanness and the latter group more aligned with the African ideal of overweight/obesity as the preferred body size. It is recommended that more in-depth studies of these groups are necessary to determine whether these assumptions are correct and to investigate whether obesity intervention programs would require different approaches in each of these populations.

Supporting Information

S1 Table. Comparison between body composition, lifestyle and psychosocial characteristics of black African women with and without DXA data at both time points.
(DOCX)

S2 Table. Comparison between baseline FID groups at baseline for follow-up body composition measures.
(DOCX)

S3 Table. Comparison between PAD groups at baseline for follow-up body composition measures.
(DOCX)

Author Contributions

Conceived and designed the experiments: PJLG SAN LKM NJC. Performed the experiments: PJLG. Analyzed the data: PJLG NJC. Contributed reagents/materials/analysis tools: PJLG SAN LKM NJC. Wrote the paper: PJLG.

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APPENDIX 11: SUPPLEMENTARY TABLE 3.1

Supplementary Table 3.1: Multiple regression models for anthropometric and metabolic variables using observed data

Dependent variable	**N**	**Independent variables**	**Coefficients (95% Confidence Interval)‡**	**Beta Coefficients† (p-value)**	**Adjusted R^2 (p-value)**
Fasting blood glucose	530	Age Waist circumference	0.0013 (0.0002, 0.0025) 0.0008 (0.00001, 0.0015)	0.09 (0.03) 0.10 (0.03)	0.02 (0.002)
Fasting insulin	310	Age Waist circumference	-0.003 (-0.006, 0.0009) 0.007 (0.004, 0.009)	-0.08 (0.15) 0.31 (<0.001)	0.09 (<0.001)
High density lipoprotein cholesterol	455	Age Waist circumference	-0.002 (-0.006, 0.0011) -0.003(-0.005, -0.0004)	-0.06 (0.18) -0.12 (0.02)	0.02 (0.006)
Low density lipoprotein cholesterol	455	Age Waist circumference	0.007 (0.004, 0.009) 0.002 (0.0008, 0.004)	0.26 (<0.001) 0.14 (0.002)	0.11 (<0.001)
Total cholesterol	456	Age Waist circumference Walking for travel	0.05 (0.03, 0.07) 0.008 (-0.005, 0.02) -0.0004(-0.0009, 0.00008)	0.23 (<0.001) 0.06 (0.23) -0.09 (0.05)	0.07 (<0.001)
Systolic blood pressure	602	Age Waist circumference	0.002 (0.0015, 0.003) 0.0009 (0.0006, 0.001)	0.23 (<0.001) 0.17 (<0.001)	0.10 (<0.001)
Diastolic blood pressure	599	Age Waist circumference Sitting time	0.21 (0.11, 0.32) 0.20 (0.13, 0.26) 0.001 (0.0002, 0.002)	0.13 (<0.001) 0.20 (<0.001) 0.08 (0.01)	0.07 (<0.001)
Fat mass	636	Age SES score	238 (139, 337) 66.8 (25.5, 108)	0.18 (0.001) 0.12 (0.002)	0.05 (<0.001)
Fat free soft tissue mass	636	Age SES score Work MVPA	13.2 (-43.4, 69.8) 27.6 (3.93, 51.2) 0.69 (0.12, 1.26)	0.02 (0.65) 0.09 (0.02) 0.09 (0.02)	0.02 (<0.001)
Waist	925	Age	0.35 (0.25, 0.45)	0.21 (<0.001)	0.04

circumference					(<0.001)

APPENDIX 12: SUPPLEMENTARY TABLE 3.2

Supplementary Table 3.2: Pearson's correlations for body composition and metabolic outcomes

Variable	Fasting glucose	Fasting insulin	HOMA	HDL	LDL	Triglycerides	Total cholesterol	Systolic blood pressure	Diastolic blood pressure	Total body fat	Fat-free, soft-tissue mass	Waist circumference
Age	0.12 (<0.001)	0.01 (0.84)	-0.08 (0.02)	-0.09 (0.01)	0.31 (<0.001)	0.08 (0.02)	0.27 (<0.001)	0.28 (<0.001)	0.18 (<0.001)	0.15 (<0.001)	0.01 (<0.82)	0.21 (<0.0001)
SES score	-0.01 (0.88)	0.07 (0.045)	0.74 (0.04)	0.01 (0.84)	-0.04 (0.70)	-0.03 (0.38)	0.04 (0.22)	-0.08	-0.05	0.15	0.08	0.21
Sitting time	0.03 (0.45)	0.004 (0.90)	-0.02 (0.51)	0.09 (0.01)	-0.07 (0.04)	0.12 (<0.0001)	-0.11 (0.001)	0.04 (0.22)	0.07 (0.03)	-0.06 (0.05)	-0.04 (0.17)	-0.04 (0.07)
Total MVPA	0.08 (0.01)	-0.10 (0.002)	-0.14 (<0.001)	0.09 (0.01)	-0.05 (0.14)	0.06 (0.06)	-0.06 (0.08)	0.04 (0.26)	0.05 (0.16)	0.01 (0.69)	0.05 (0.14)	0.05 0.13)
Total work MVPA	0.03 (0.31)	-0.09 (0.01)	-0.12 (<0.001)	0.10 (0.003)	-0.01 (0.71)	0.06 (0.09)	-0.04 (0.19)	0.03 (0.36)	0.02 (0.55)	0.02 (0.57)	0.71 (0.03)	0.05 (0.14)
Total walking for travel	0.11 (0.001)	0.01 (0.75)	-0.02 (0.42)	0.78 (0.02)	-0.07 (0.03)	0.03 (0.33)	-0.10 (0.004)	-0.003 (0.93)	0.04 (0.18)	-0.01 (0.72)	-0.04 (0.27)	0.002 (0.94)
Total leisure MVPA	0.03 (0.41)	-0.02 (0.50)	-0.04 (0.27)	0.02 (0.55)	-0.09 (0.01)	0.02 (0.53)	-0.10 (0.004)	0.02 (0.53)	0.03 (0.32)	-0.002 (0.95)	0.03 (0.32)	0.02 (0.50)
Total fat mass	0.09 (0.02)	0.30 (<0.001)	0.21 (<0.001)	-0.11 (0.01)	0.15 (<0.001)	0.05 (0.19)	0.08 (0.06)	0.18 (<0.001)	0.25 (<0.001)	-	0.74 (<0.001)	0.85 (<0.0001)
Fat-free, soft-tissue mass	0.09 (0.004)	0.23 (<0.001)	0.15 (<0.001)	-0.09 (0.01)	0.14 (<0.001)	0.02 (0.54)	0.06 (0.07)	0.12 (<0.001)	0.15 (<0.001)	0.79 (<0.001)	-	0.75 (<0.0001)
Waist circumference	0.13 (<0.001)	0.32 (<0.001)	0.21 (<0.001)	-0.17 (<0.001)	0.24 (<0.001)	0.04 (0.23)	0.14 (<0.001)	0.24 (<0.001)	0.25 (<0.001)	0.83 (<0.001)	0.75 (<0.001)	-

APPENDIX 13: SUPPLEMENTARY TABLE 4.1

Supplementary Table 4.1: Comparison between body composition, lifestyle and psychosocial characteristics of black African women with and without DXA data at both time points

Variable	Women with DXA at both time points (n=264)	Women without DXA at both time points (n=164)
Age (years)	42.0 ± 5.50	39.4 ± 4.62*
Body mass index ($kg.m^{-2}$)	30.5 ± 6.32	31.3 ± 7.33
Waist circumference (cm)	88.3 ± 12.9	86.2 ± 13.6
Hip circumference (cm)	113 ± 12.9	115 ± 15.0
Sitting time ($mins.wk^{-1}$)	1260 (840-1680)	1260 (840-2100)
Physical activity ($mins.wk^{-1}$)	300 (140-840)	480 (180-1440)
Current smokers	9 (3.53%)	4 (2.86%)
Alcohol use	47 (18.4%)	25 (17.6%)
Feel minus ideal index (FID)	0.92 ± 1.53	1.24 ± 1.62
Perceived minus actual weight status discrepancy score (PAD)	-0.95 ± 0.75	-0.84 ± 0.68

*P<0.005; data given as mean ± SD, median (interquartile range) or n (%)

APPENDIX 14: SUPPLEMENTARY TABLE 4.2

Supplementary Table 4.2: Comparison between baseline FID groups at baseline for follow-up body composition measures

Variable	Subjects who wanted to be fatter	Subjects who were content with their body shape	Subjects who wanted to be leaner
BMI ($kg.m^{-2}$)	26.5 ± 4.90 (44)	31.0 ± 5.65(137)†	35.5 ± 7.50 (247)††† ***
Waist circumference (cm)	87.7 ± 12.3 (43)	94.7 ± 11.5 (134)	103 ± 15.1 (238)††† ***
Hip circumference (cm)	105 ± 10.9 (43)	114 ± 11.5 (133)	123 ± 15.6 (237)††† ***
Fat mass (kg)	24.2 ± 9.0 (32)	31.4 ± 9.53 (84)	35.4 ± 10.1 (148)††† *
Fat free soft tissue mass (kg)	41.6 ± 7.08 (32)	43.5 ± 6.24 (84)	46.7 ± 7.48 (264)††† ***
Central adiposity (kg)	10.1 ± 4.34 (30)	13.5 ± 4.69 (84)	15.8 ± 5.32 (147)††† *
Peripheral adiposity (kg)	13.2 ± 4.75 (30)	17.1 ± 5.51 (84)	19.1 ± 5.71 (147)††† *

Data presented as mean ± SD (n); $^{\dagger}P<0.05$, $^{\dagger\dagger\dagger}P<0.0005$ versus subjects who wanted to be fatter; $^{*}P<0.05$, $^{***}P<0.0005$ versus subjects who were content with body shape; abbreviation, body mass index (BMI)

APPENDIX 15: SUPPLEMENTARY TABLE 4.3

Supplementary Table 4.3: Comparison between PAD groups at baseline for follow-up body composition measures

Variable	Subjects who underestimated actual body weight	Subjects who accurately perceived actual body weight	Subjects who overestimated actual body weight
BMI ($kg.m^{-2}$)	34.7 ± 6.57 (316)	29.0 ± 7.62 (103)	23.3 ± 4.37 (9)††† ***
Waist circumference (cm)	102 ± 13.5 (307)	90.8 ± 14.7 (97)	82.7 ± 11.1 (9)††† *
Hip circumference (cm)	121 ± 13.9 (306)	111 ± 15.5 (96)	99.1 ± 11.2 (9)††† *
Fat mass (kg)	35.2 ± 9.65 (198)	26.3 ± 9.82 (59)	18.3 ± 9.06 (6)††† ***
Fat free soft tissue mass (kg)	46.8 ± 6.69 (198)	40.6 ± 6.20 (59)	32.5 ± 3.85 (6)††† ***
Central adiposity (kg)	15.8 ± 4.71 (196)	10.6 ± 4.83 (58)	7.28 ± 4.23 (6)††† ***
Peripheral adiposity (kg)	18.9 ± 5.49 (196)	14.9 ± 5.41 (58)	10.2 ± 5.16 (6)

Data presented as mean ± SD (n); $^{\dagger}P<0.05$, $^{\dagger\dagger\dagger}P<0.0005$ versus subjects who underestimated actual body weight; $^{*}P<0.05$, $^{***}P<0.0005$ versus subjects who accurately perceived actual body weight; abbreviation, body mass index (BMI)

APPENDIX 16: SUPPLEMENTARY TABLE 5.1

Supplementary Table 5.1: Anthropometric and metabolic variables in women with and without metabolic syndrome[†]

Variables	Women with metabolic syndrome[†] (n=320)	Women without metabolic syndrome (n=325)
Age (years)	50.1 ± 5.33	48.5 ± 5.13**
BMI ($kg.m^{-2}$)	35.4 ± 6.6	30.9 ± 6.98***
Waist (cm)	104 ± 11.6	93.4 ± 14.4***
Hip (cm)	122 ± 13.5	114 ± 14.6***
Arm fat (kg)	4.08 ± 1.14	3.36 ± 1.25***
Arm FFSTM (kg)	4.70 ± 0.86	4.20 ± 0.75***
Leg fat (kg)	14.8 ± 4.31	13.5 ± 4.72***
Leg FFSTM (kg)	16.3 ± 2.77	14.9 ± 2.78***
Trunk fat (kg)	16.1 ± 4.37	12.7 ± 5.15***
Trunk FFSTM (kg)	23.0 ± 3.18	20.6 ± 3.08***
Total body fat (kg)	35.0 ± 8.76	29.5 ± 10.3***
Total FFSTM (kg)	44.0 ± 6.43	39.7 ± 6.26***
Subcutaneous fat thickness (cm)	3.49 ± 1.01	3.35 ± 1.03
Visceral fat thickness (cm)	4.89 ± 1.54	3.94 ± 1.76***
Systolic blood pressure (mmHg)	138 [128, 150]	121 [113, 136]***
Diastolic blood pressure (mmHg)	91.5 [86.5, 99.5]	81.2 [75.0, 90.5]***
HbA1c (%)	5.90 [5.60, 6.50]	5.70 [5.40, 6.10]***
Fasting glucose ($mmol.L^{-1}$)	5.00 [4.60, 5.70]	4.60 [4.30, 4.90]***
Insulin ($pmol.L^{-1}$)	12.0 [7.80, 17.3]	8.32 [5.65, 12.8]***
HOMA	2.65 [1.75, 4.45]	1.76 [1.19, 2.69]***
Adiponectin ($\mu g.mL^{-1}$)	5.91 [3.78, 8.62]	8.47 [5.51, 12.6]***
Leptin ($ng.mL^{-1}$)	31.1 [18.6, 45.9]	22.7 [13.1, 40.5]***
Total cholesterol ($mmol.L^{-1}$)	4.38 ± 1.04	4.61 ± 1.05
LDL ($mmol.L^{-1}$)	2.71 ± 0.88	2.75 ± 0.90
HDL ($mmol.L^{-1}$)	1.10 [0.90, 1.20]	1.40 [1.10, 1.60]***
Triglycerides ($mmol.L^{-1}$)	1.30 [0.90, 1.70]	1.00 [0.70, 1.30]***
Employed (%)	57.5 (52.1, 62.9)	57.7 (52.3, 63.1)
Completed high school education (%)	26.6 (21.7, 31.5)	33.6 (28.4, 38.9)
Smokers (%)	9.37 (6.16, 12.6)	7.38 (4.53, 10.2)
Consume snuff (%)	19.1 (14.8, 23.5)	21.4 (16.9, 25.9)

[†]Metabolic syndrome diagnosis was made in subjects in whom 3 or more of the following 5 variables exceeded the cut points set out by the harmonised guidelines (2): waist circumference, blood pressure, glucose, triglyceride and HDL levels; data expressed as mean ± SD or median [interquartile range] or % (95% CIs); BMI: body mass index; FFSTM: fat–free, soft– tissue mass; HOMA: homeostasis model assessment; $^{*}p < 0.05$, $^{**}p < 0.005$, $^{***}p < 0.0005$ vs women with metabolic syndrome

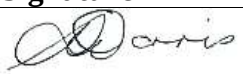
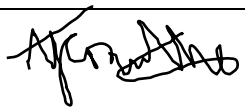
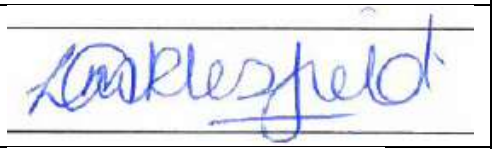
APPENDIX 17: CO–AUTHOR AGREEMENT

The following publication titles are part of a doctoral thesis:

1. The role of lifestyle and psycho-social factors in predicting changes in body composition in black South African women
2. Patterns, levels and correlates of self-reported physical activity in urban black Soweto women
3. Metabolic and body composition risk factors associated with metabolic syndrome in a cohort of women with a high prevalence of cardiometabolic disease

Philippe J. Gradidge was involved in the conceptual design, data collection, statistical analyses and interpretation, and writing of all three publications.

The co–authors have been informed and are in agreement that these publications may be used as part of his thesis.

Name	**Signature**
Shane A. Norris	
Nigel J. Crowther	
Lisa K. Micklesfield	
Esnat D. Chirwa	
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