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ORIGINAL ARTICLE

Obesity and regional fat distribution in Kenyan populations: Impact of ethnicity and urbanization

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Abstract

Background: Obesity is increasing rapidly in Africa, and may not be associated with the same changes in body composition among different ethnic groups in Africa.

Objective: To assess abdominal visceral and subcutaneous fat thickness, prevalence of obesity, and differences in body composition in rural and urban Kenya.

Subjects and methods: In a cross-sectional study carried out among Luo, Kamba and Maasai in rural and urban Kenya, abdominal visceral and subcutaneous fat thicknesses were measured by ultrasonography. Height and weight, waist, mid-upper arm circumferences, and triceps skinfold thickness were measured. Body mass index (BMI), arm fat area (AFA) and arm muscle area (AMA) were calculated.

Results: Among 1430 individuals (58.3% females) aged 17–68 years, abdominal visceral and subcutaneous fat, BMI, AFA and waist circumference (WC) increased with age, and were highest in the Maasai and in the urban population. AMA was only higher with increasing age among males. The prevalence of overweight ($BMI \geq 25$) (39.8% vs. 15.8%) and obesity ($BMI \geq 30$) (15.5% vs. 5.1%) was highest in the urban vs. rural population.

Conclusion: Abdominal visceral and subcutaneous fat thickness was higher with urban residency. A high prevalence of overweight and obesity was found. The Maasai had the highest overall fat accumulation.

Keywords: *Kenya, visceral fat, ultrasonography*

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Introduction

The prevalence of overweight and obesity is increasing more rapidly in the developing world than in Europe and the USA (Popkin 2002). The hypothesized primary reasons for this increase in obesity prevalence is an increase in intake of saturated fat, sugar and low fibre refined foods, often termed 'Western diet', and a decrease in physical activity against changes in availability of food and a decrease in infectious diseases (Popkin 2002). Consequently, an increase in the incidence of chronic diseases including type-2 diabetes is seen (WHO 2003). These lifestyle diseases were rarely seen in developing countries in the past (Dodu and de Heer 1964; Imperato et al. 1976).

Today approximately 40% of all Africans live in urbanized areas, and Africa has the world's highest urbanization rate at over 4% per annum and by 2030, 55% of the population is expected to live in urban areas (Mosha 2001). Thus, overweight and obesity has the potential of reaching epidemic proportions in the African continent and different ethnic groups experiencing urbanization may be at equal risk of obesity based on standard clinical measures. However, body composition (i.e. fat vs. muscle, abdominal visceral fat vs. abdominal subcutaneous fat) may differ between ethnic groups due to genetic differences, or differences in energy intake and physical activity. Therefore, the consequent risk of chronic diseases may not be the same in different ethnic groups. Such relationships between nutritional status and chronic disease risks and patterns have been studied between African populations (Murray et al. 1978; Day et al. 1979; O'Keefe et al. 1988), as well as within single ethnic groups (Mann et al. 1964; Shaper et al. 1969; Ho et al. 1971; Day et al. 1976; Truswell 1977).

Studies of anthropometry in association with nutrition and demographic transition in urban populations have been conducted in South Africa for several decades (Seftel et al. 1980; Walker et al. 1990; Mollentze et al. 1995; Steyn et al. 1998), while the majority of such studies in other sub-Saharan countries are more recent (Maire et al. 1992; Gartner et al. 2000; Pasquet et al. 2003; Afolabi et al. 2004; Fezeu et al. 2005; Siervo et al. 2006). A common trait of all these investigations is higher fat accumulation as a result of urbanization and this has been observed among women in particular. In South Africa, obesity in women of ethnic African origin has been regarded as 'benign' or 'healthy' for several decades, even up to this decade (van der Merwe and Pepper 2006). However, other investigations have changed this view (Joubert et al. 2000; Vorster 2002; Joffe et al. 2004).

Previous studies have used simple anthropometric measures of obesity like BMI, waist and hip circumferences, skinfold thickness measures and mid-upper arm circumference while very few studies have measured body composition (% body fat) as, e.g. leg-to-leg bioimpedance (Gartner et al. 2000; Siervo et al. 2006). Importantly, there is evidence to suggest that visceral fat rather than abdominal subcutaneous fat accumulation is associated with increased insulin resistance and the metabolic syndrome (Kissebah et al. 1982; Krotkiewski et al. 1983). While waist–hip ratio (WHR) and waist circumference (WC) measurements do capture total abdominal fat accumulation, they do not provide a quantitative measurement of abdominal fat distribution, i.e. visceral and subcutaneous fat. Visceral and total abdominal fat may be differentially associated with risk of chronic disease (Leite et al. 2002); therefore it is important to quantify visceral fat. The gold standards for the quantitative assessment of visceral fat tissue are the computed tomography (CT) and magnetic resonance imaging (MRI) (Seidell et al. 1990). However, these methods are not feasible for clinical or epidemiological purposes due to equipment size, costs and radiation exposure. Recently, an ultrasound protocol for the assessment of intraabdominal fat was developed and validated successfully against the CT and MRI methods (Stolk et al. 2001). Using the ultrasound method in an epidemiological field setting is feasible, and direct measures of visceral and subcutaneous abdominal fat thickness could therefore provide hitherto unknown insight into the body composition among African populations in general and ethnic differences in particular.

The objective of this study was to assess the prevalence of obesity and differences in body composition with emphasis on separating abdominal visceral and subcutaneous fat compartments, and to compare these measures in rural and urban adult populations of Kenya as well as between the Luo, Kamba and Maasai.

Study population and methods

Study area and population

A cross-sectional study in Kenya based on an opportunity sample was conducted among three rural populations – the Luo, Kamba and Maasai – and in an urban population of mixed ethnic origin. All data were collected during the period August 2005 to January 2006. Among the Luo, data were collected in August–September, among the Kamba in September–October, among the Maasai in October–November, and among the urban population in December–January. The Luo are mainly subsisting on maize, sorghum and to some extent on fish (Ochieng 1979), the Kamba on maize (van Steenbergen et al. 1984), and the Maasai on animal husbandry and maize (Nestel 1989). For a geographical overview of study areas, see Figure 1.

Selection procedure

Inclusion criteria for the study was ≥17 years of age and Luo, Kamba or Maasai ethnicity in the rural areas and the same ethnicities or biologically and culturally related ethnic groups

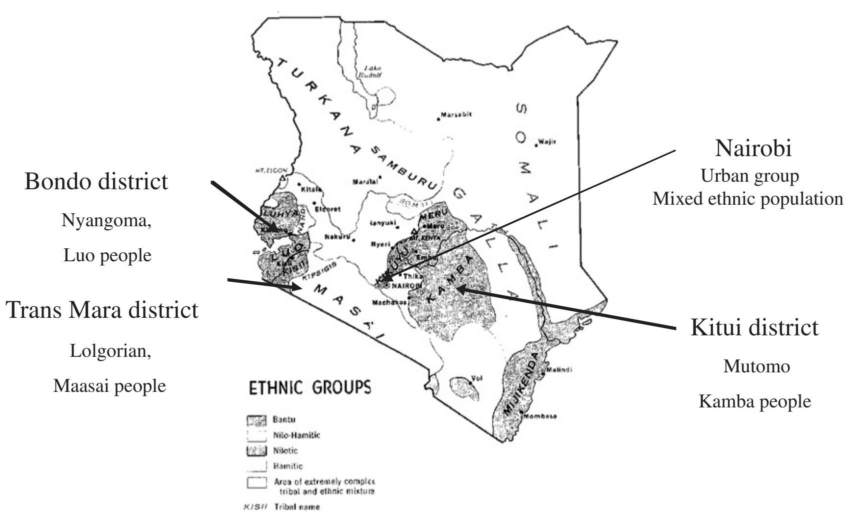

Figure 1. Map of Kenya with ethnic distribution, major cities and towns and names of study areas (map courtesy of University of Texas Libraries).

in the urban area. Exclusion criteria for participation were pregnancy, serious illnesses such as malaria, inability to walk unassisted and severe mental disease. To participate in the urban group residency ≥2 years in Nairobi was required.

A random sample based on rural populations selected by lot at public village meetings ('barazas' in Kiswahili) was attempted. However, this plan had to be abandoned as many villagers did not show up at the barazas. Biological relatives of the rural participants were supposed to have made out the urban study participants, but this turned out not to be feasible as many did not wish to participate. All potential participants were presented with a standard statement by a local social mobilizer, describing the current study as a diabetes survey including a general health check.

Subsequently, all interested individuals were registered for participation and assigned a specific day to show up at the study site. In case the registered individuals did not show up for participation, they were substituted by volunteers not registered but who showed up at the study site for the purpose of enrolment in the study. The Luo participants were examined at 13 different primary schools in six different sub-locations of Bondo district around Lake Victoria, The Kamba participants were examined at Mutomo Hospital in Kitui District in eastern Kenya, but they lived in three different sub-locations within a range of 20 km from the study site. The Maasai participants were examined at Lolgorian Health Centre, and they all lived in villages ('manyattas') within a 20 km range from the study site. In all, 407 Luo (224 females, 183 males), 406 Kamba (300 females, 106 men) and 365 Maasai (193 women, 172 men) from the rural areas participated in the study.

The capital city of Nairobi was chosen as the study site for the urban participants. Potential participants were approached individually or in groups by social mobilizers for registration at their work or during church services. The study populations included the Luo as well as a cluster of Kamba, Kikuyu, Embu and Meru and a cluster of Maasai and Kalenjin. Each cluster is known to be biologically and culturally closely intra-linked through intermarriage within the groups (Fedders and Salvadori 1979; Muriuki 1985). Hence, throughout the text the two urban clusters will be described as Kamba and Maasai, respectively. Evidence for genetic difference between peoples of Bantu descent (i.e. Kamba) and Nilotic descent (i.e. Luo and Maasai) have been shown by Cavalli-Sforza et al. (1994).

The urban study participants were examined in four different locations including a university, a primary school, and two churches scattered around Nairobi in order to capture participants from all social groups. In all, 252 urban individuals of mixed ethnic origin participated, and of these 72 were Luo (18 females, 54 males), 173 were Kamba (98 females, 75 males), and seven were Maasai (all males).

The age of all the participants was taken from their personal ID cards, or by their own account. If the participant did not know his or her age – this was especially apparent among the Maasai – the local social mobilizer estimated their age according to personal events such as circumcision and age-set membership.

All participants gave written or oral informed consent. The study was approved by the National Ethical Review Committee in Kenya and the Danish National Committee on Biomedical Research Ethics in Denmark.

Anthropometry

All anthropometric measurements were carried out after an overnight fast, with the participants standing barefooted and wearing light clothing only. Weight was measured to the nearest 0.1 kg using a portable high precision scale (TANITA, type BWB-800 S MA, Tokyo, Japan), and height was measured to the nearest 0.1 cm with a portable stadiometer (Meterex II, D97, UNICEF, Copenhagen, Denmark). Body mass index (BMI) was calculated as weight/height^2 (kg/m^2). Waist and hip circumference was measured with a body tape (Chasmors WM02 Body Tape, Haechstmass, Germany) with waist circumference (WC) measured midway between the iliac crest and the costal margin following a quiet expiration. Mid-upper arm circumference (MUAC) was measured on the left arm to the nearest 0.1 cm at the midpoint of the humerus without compressing the tissue using Babytape (Raven Equipment, Dunmow, Essex, UK) and triceps skinfold thickness (TSF) on the left arm to the nearest 0.1 mm at the midpoint of the humerus using a Harpenden caliper (Model HSB-BI, British Indicators, Burgess Hill, UK). Arm muscle area (AMA) and arm fat area (AFA) were calculated, without adjusting for bone area, according to Frisancho (1990). Two local assistants performed the measurements in each study area. Measurements to determine inter- or intra-observer variations were not carried out.

Overweight was defined as BMI $\geq$ 25 kg m^{-2}, and BMI $\geq$ 30 kg m^{-2} defined obesity, while underweight was defined as BMI < 18.5 kg m^{-2}. WC above 88 cm and 102 cm for women and men, respectively, were considered abdominally obese (WHO 2000).

Ultrasonography

Abdominal fat distribution was measured using ultrasonography (Aquila Basic Unit, Esaote, Pie Medical Equipment, Maastricht, the Netherlands) with a 3.5/5.0 MHz transducer (Probe Article no. 410638 Curved Array HiD probe R40 Pie Medical Equipment). The validity and reproducibility for the assessment of intra-abdominal visceral fat compared to computed tomography and magnetic resonance imaging has previously been evaluated in a study population of 19 obese individuals (average BMI 32.9 kg m^{-2}) (Stolk et al. 2001). A straight line was drawn between the iliac crest and the costal margin. The mid-point of this line on both sides was marked with the subject standing. A straight line was drawn between the left and right midpoint after the subject had changed to a supine position lying on his back. Three new marks were drawn on this line marking the point for the visceral, i.e. intra-abdominal measurements (centrally just above the navel and 10 cm distally in a straight line to both sides) with the transducer. Visceral fat measurements were done from the spine to the linea alba with minimal pressure at the end of a quiet expiration. Subcutaneous fat was measured from the muscles to the skin and with no pressure on the skin. All measurements were recorded in centimetres and were performed by two trained investigators. The results of the visceral fat measurements were derived from a mean of the three – i.e. central, left and right – abdominal measurements. Subcutaneous fat thickness was determined from one measurement with the transducer placed centrally just above the navel on the marked midpoint as described above. Measurements to determine inter- or intra-observer variations were not carried out.

Statistics

The chi-square test was used to test for differences in proportions, the two sample *t*-test and one-way analysis of variance, with Bonferroni–Dunn *post hoc* test, were used to test for differences in means. We used BMI, visceral fat, subcutaneous fat, AMA, AFA and WC as dependent variables in multiple linear regressions with age, gender, ethnicity and residency as explanatory variables. Data on males and females were analysed separately. Multiple linear regression analysis was used, stratified by gender, to assess the role of urban residence while controlling for age and ethnicity and in the analysis of visceral fat, also controlling for weight and height. Further, we tested for interaction between age and residency, age and ethnicity, and ethnicity and residency. Age 55 was used as reference. We reported residual SD as a measure of accuracy of prediction by the models. Normal and residual-versus-fitted plots were examined to assess normality and homoscedasticity of residuals. All analyses were done with the Stata 9.0 Intercooled version (Stata Corp, College Station, TX, USA).

Results

In total, 1430 individuals (1178 rural, 252 urban) participated in the study. Background characteristics of ethnic populations stratified by gender are shown in Table I. Among females, the mean age was higher in the urban compared to the rural population (40.9 vs. 38.4 years, $p < 0.016$), whereas among males the mean age was lower in the urban compared to the rural population (33.9 vs. 40.0 years, $p < 0.001$).

The Kamba males weighed less and were shorter in the rural and urban populations, and had a narrower waist in the rural population compared to the Luo and Maasai (Table II). For females, the rural Kamba weighed less and were shorter than their Luo and Maasai counterparts, while the urban Kamba had a larger waist than the urban Luo.

Among males, rural Kamba had the lowest BMI and AFA, while the rural Luo had the highest AMA and the rural and urban Maasai had the highest AFA (Table III). In females, the Kamba had the highest AMA among rural and urban residents and the highest BMI and AFA (marginally significant, $p = 0.094$ and $p = 0.076$, respectively). The Maasai had the highest AFA in the rural area. For abdominal fat distribution, the male Kamba had the lowest visceral fat thickness, while the Maasai had the highest subcutaneous fat thickness in the rural area. Among women, the urban Luo had lower visceral and subcutaneous fat thickness compared to the Kamba and the lowest subcutaneous fat thickness in the rural population.

In relative terms, when controlled for weight, height, age and residency, the male Luo had the lowest visceral fat thickness ($p < 0.001$), while the Maasai maintained the highest visceral fat thickness ($p < 0.001$). Among the females, the Luo maintained the lowest visceral fat thickness ($p < 0.001$) while no difference could be found between the Maasai and Kamba ($p = 0.116$).

Mean (±SD) visceral-to-subcutaneous fat ratio among females was 7.3 (5.5), 4.6 (4.4) and 5.3 (4.0) ($p < 0.001$) in Luo, Kamba, and Maasai, respectively. Among males, the Luo had 11.9 (8.1), the Kamba 8.6 (6.5), and the Maasai 11.1 (8.0) ($p < 0.001$).

The prevalence of overweight (BMI $\geq 25\,kg\,m^{-2}$) in the rural and urban populations was 19.5 and 60.3%, and 10.0% and 22.6% for females and males, respectively. The corresponding prevalence of obesity (BMI $\geq 30\,kg\,m^{-2}$) was 6.7% and 25.9% among females and 2.8% and 6.6% for males, respectively. The prevalence of underweight was 16.6% and 5.2% in females, 23.4% and 11.7% in males. Abdominal (or central) obesity as defined by WC (88 cm and 102 cm for women and men, respectively) in rural and urban

Table I. Background characteristics by ethnic group and residence.

	Luo ($n=479$)	Kamba ($n=579$)	Maasai ($n=372$)	p-value
Residence (%)				
Rural	34.5	34.5	31.0	<0.001
Urban	28.7	68.5	2.8	<0.001
Female (%)				
Rural	31.3	41.8	26.9	<0.001
Urban	16.1	83.9	0.00	<0.001
Male (%)				
Rural	39.7	23.1	37.2	<0.001
Urban	39.7	55.1	5.2	<0.001
Age (years)				
Female				
Rural*	39.0^{a} (9.8)	40.4^{a} (9.5)	34.6^{b} (11.1)	<0.001
	20–62	17–63	17–68	
Urban*	32.5 (10.0)	42.5 (11.2)		<0.001
	18–63	18–63		
Male				
Rural*	40.0^{ab} (10.1)	42.4^{a} (9.7)	38.4^{b} (11.1)	0.015
	19–67	20–60	19–68	
Urban*	30.8^{ac} (9.9)	36.7^{bc} (11.6)	27.5^{c} (2.3)	0.002
	18–56	19–60	24–30	

Notes: *Values are mean (±SD) (first row) and age range (second row).
^{abc} Values within a row with different superscript letters are significantly different ($p<0.05$).

populations, respectively, was seen in 13.4% and 46.6% of the females, but only 4.8% and 11.1% of the males, respectively.

Multi-variable analysis

Abdominal visceral and subcutaneous fat, BMI, AFA and WC increased with increasing age, and more so among urban compared to rural residents (interaction, $p<0.001$), as seen in Tables IV–VI. For both genders we found different age effects among urban and rural residents. Thus, the effect of age was modified by residency. Since we use different age-effects for urban and rural residents, we report the urban–rural difference at the same specific age.

We chose 55 years to show the accumulated effect on body composition parameters in the upper part of the age range and to compensate for the uneven age distribution between the ethnic groups and rural vs. urban groups. For example, BMI of 55-year-old Luo females in rural residency was 22.8 kg m^{-2} (Table V and Figure 2). The women in urban residency had 6.3 kg m^{-2} (95% CI: 4.9, 7.8) higher BMI ($p<0.001$) at age 55 years. For every 10 years of age, BMI increased 1.9 kg m^{-2} among urban women, but only 0.6 kg m^{-2} among rural women (interaction, $p<0.001$) after ethnicity was adjusted for. The effect of ethnicity was small, with 0.8 kg m^{-2} for the Maasai ($p=0.079$) and 0.6 kg m^{-2} for the Kamba ($p=0.088$) compared to the Luo.

Table II. Anthropometric measurements by ethnic group, gender and residence. All data are mean values (±SD).

	Luo ($n=479$)	Kamba ($n=579$)	Maasai ($n=372$)	p-value
Weight (kg)				
Female				
Rural	58.0^{a} (10.1)	55.5^{b} (12.2)	58.2^{a} (12.7)	0.015
Urban	68.6 (17.2)	68.5 (14.0)	–	0.975
Male				
Rural	64.3^{a} (10.4)	56.5^{b} (9.0)	63.9^{a} (14.7)	<0.001
Urban	68.5(13.3)	63.8(11.6)	74.9(15.4)	0.019
Height (cm)				
Female				
Rural	163.1^{a} (6.1)	156.8^{b} (5.9)	161.4^{c} (6.0)	<0.001
Urban	165.5 (5.3)	158.2 (5.4)	–	<0.001
Male				
Rural	174.2^{a} (6.6)	167.9^{b} (6.7)	174.1^{a} (6.7)	<0.001
Urban	174.2^{a} (6.2)	168.3^{b} (6.4)	179.2^{a} (1.6)	<0.001
Waist (cm)				
Female				
Rural	77.4 (8.5)	77.5 (10.2)	78.4 (11.5)	0.537
Urban	80.3 (12.0)	88.6 (12.9)	–	0.012
Male				
Rural	78.9^{ab} (8.6)	76.9^{a} (7.4)	80.3^{b} (13.2)	0.024
Urban	82.6 (17.4)	82.8 (14.3)	85.3 (10.4)	0.908
Hip (cm)				
Female				
Rural	91.2^{a} (8.5)	92.2^{a} (9.7)	94.9^{b} (9.6)	<0.001
Urban	102.3 (14.4)	105.5 (12.3)	–	0.323
Male				
Rural	88.8^{a} (6.4)	87.1^{b} (5.9)	90.7^{a} (9.6)	<0.001
Urban	94.7 (15.2)	93.0 (7.6)	99.8 (9.8)	0.269
Mid-upper arm circumference (cm)				
Female				
Rural	27.7 (3.8)	28.5 (4.6)	28.6 (4.8)	0.061
Urban	28.0 (4.7)	31.1 (5.0)	–	0.015
Male				
Rural	27.2^{ac} (2.9)	25.6^{bc} (2.6)	26.5^{c} (4.3)	<0.001
Urban	28.4 (3.1)	27.6 (3.4)	30.0 (3.2)	0.105
Triceps skinfold thickness (mm)				
Female				
Rural	17.2^{a} (8.3)	15.4^{b} (7.6)	19.0^{c} (7.9)	<0.001
Urban	24.8 (13.6)	29.1 (11.6)	–	0.165
Male				
Rural	8.8^{a} (4.8)	8.7^{a} (4.4)	12.0^{b} (9.4)	<0.001
Urban	12.8 (10.3)	11.9 (6.1)	18.6 (10.5)	0.113

Note: ^{abc}Values within a row with different superscript letters are significantly different ($p<0.05$).

Table III. Derived anthropometric variables and abdominal fat distribution by ethnic group, gender and residence. All data are mean values (±SD).

	Luo ($n = 479$)	Kamba ($n = 579$)	Maasai ($n = 372$)	p-value
Body mass index ($kg\,m^{-2}$)				
Female				
Rural	21.8 (3.7)	22.5 (4.4)	22.3 (4.7)	0.135
Urban	25.0 (5.8)	27.4 (5.5)	–	0.094
Male				
Rural	21.2^{a} (3.0)	20.0^{b} (2.6)	21.0^{a} (4.7)	0.021
Urban	22.5 (3.8)	22.5 (3.9)	23.3 (4.4)	0.872
Arm muscle area (cm^2)				
Female				
Rural	40.1^{a} (9.9)	45.3^{b} (10.8)	41.3^{a} (11.0)	<0.001
Urban	33.1 (9.2)	39.4 (14.0)	–	0.066
Male				
Rural	47.8^{a} (8.2)	42.0^{bc} (6.8)	41.5^{c} (8.1)	<0.001
Urban	48.0 (10.4)	45.9 (11.5)	46.9 (8.0)	0.582
Arm fat area (cm^2)				
Female				
Rural	22.1^{a} (13.4)	21.1^{a} (13.3)	25.5^{b} (14.6)	0.002
Urban	30.9 (19.9)	39.6 (19.0)	–	0.076
Male				
Rural	11.7^{a} (7.5)	10.8^{a} (6.4)	15.9^{b} (15.7)	<0.001
Urban	16.8^{ab} (11.6)	15.5^{a} (8.6)	25.6^{b} (15.7)	0.050
Waist–hip ratio				
Female				
Rural	0.85^{a} (0.05)	0.84^{a} (0.05)	0.82^{b} (0.06)	<0.001
Urban	0.79 (0.07)	0.84 (0.06)	–	0.002
Male				
Rural	0.89 (0.05)	0.88 (0.04)	0.88 (0.506)	0.561
Urban	0.87 (0.06)	0.89 (0.10)	0.85 (0.36)	0.341
Visceral fat (cm)				
Female				
Rural	6.18 (1.12)	6.13 (1.40)	6.39 (1.49)	0.099
Urban	5.32 (1.48)	6.60 (1.82)	–	0.009
Male				
Rural	6.81^{a} (1.66)	6.15^{b} (1.46)	7.14^{a} (1.82)	<0.001
Urban	6.75 (1.51)	6.89 (2.04)	6.93 (1.46)	0.904
Subcutanous fat (cm)				
Female				
Rural	1.29^{a} (0.96)	1.84^{b} (1.17)	1.86^{b} (1.22)	<0.001
Urban	2.01 (1.08)	2.94 (1.29)	–	0.007
Male				
Rural	0.73^{a} (0.50)	0.94^{ab} (0.69)	1.06^{b} (0.94)	<0.001
Urban	1.17 (0.87)	1.46 (1.10)	1.86 (0.81)	0.106

Note: [abc]Values within a row with different superscript letters are significantly different ($p < 0.05$).

Table IV. Predictors of abdominal visceral fat (cm) and subcutaneous fat (cm) stratified by gender with linear regression coefficients (*B*), 95% confidence intervals (CI) and *p*-values*.

	B (cm)	95% CI	*p*-value
Adominal viceral fat			
Female($n=818$)†			
Intercept (abdominal visceral fat at 55 years)	6.4	6.2; 6.6	<0.001
Urban	1.0	0.6, 1.5	<0.001
Age (cm, 10 years)			
Urban	0.7	0.5, 0.9	<0.001
Rural	0.2	0.05, 0.3	0.005
Ethnicity			
Kamba vs. Luo	−0.03	−0.3, 0.2	0.798
Maasai vs. Luo	0.3	0.03, 0.6	0.030
Male($n=591$)‡			
Intercept (abdominal visceral fat at 55 years)	7.2	6.9; 7.5	<0.001
Urban	2.0	1.3, 2.7	<0.001
Age (cm, 10 years)			
Urban	0.9	0.7, 1.2	<0.001
Rural	0.3	0.1, 0.4	<0.001
Ethnicity			
Kamba vs. Luo	−0.6	−1.0, −0.3	<0.001
Maasai vs. Luo	0.4	0.1, 0.7	0.012
Abdominal subcutaneous fat			
Female ($n=819$)§			
Intercept (abdominal subcutaneous fat at 55 years)	1.8	1.6; 1.9	<0.001
Urban	1.2	0.9, 1.6	<0.001
Age (cm, 10 years)			
Urban	0.4	0.2, 0.6	<0.001
Rural	0.3	0.2, 0.4	<0.001
Ethnicity			
Kamba vs. Luo	0.5	0.3, 0.7	<0.001
Maasai vs. Luo	0.7	0.5, 0.9	<0.001
Male ($n=590$)¶			
Intercept (abdominal subcutaneous fat at 55 years)	1.1	0.9; 1.2	<0.001
Urban	1.3	1.0, 1.6	<0.001
Age (cm, 10 years)			
Urban	0.5	0.4, 0.6	<0.001
Rural	0.2	0.1, 0.3	<0.001
Ethnicity			
Kamba vs. Luo	0.1	−0.05, 0.2	0.178
Maasai vs. Luo	0.4	0.2, 0.5	<0.001

Notes: *Urban residence was coded 1 if yes and 0 if no. Luo was used as reference category. Age was subtracted 55 years from each individual age to let the intercept reflect the mean of those at zero value of explanatory variables, i.e. Luo and rural dwellers aged 55 years.
†Interaction between urban residence and age, residual SD = 1.4.
‡Interaction between urban residence and age, residual SD = 1.6.
§Interaction between urban residence and age, residual SD = 1.1.
¶Interaction between urban residence and age, residual SD = 0.7.

For 55-year-old Luo males in rural residency, BMI was 22.0 kg m^{-2} (Table V and Figure 3). The men in urban residency had 5.4 kg m^{-2} (95% CI: 4.0, 6.9) higher BMI ($p<0.001$). For every 10 years of age, BMI increased 2.0 kg m^{-2} among urban men, while the increase was only 0.6 kg m^{-2} among rural men (interaction, $p<0.001$) after ethnicity

Table V. Predictors of body mass index (kg m^{-2}) and waist–hip ratio stratified by gender with linear regression coefficients (*B*), 95% confidence intervals (CI) and *p*-values*.

	B (kg m^{-2})	95% CI	*p*-value
BMI			
Female ($n = 826$)†			
Intercept (BMI at 55 years)	22.8	22.0, 23.6	0.002
Urban	6.3	4.9, 7.8	<0.001
Age (kg m^{-2}, 10 years)			
Urban	1.9	1.2, 2.6	<0.001
Rural	0.6	0.3, 0.9	<0.001
Ethnicity			
Kamba vs. Luo	0.6	−0.1, 1.4	0.088
Maasai vs. Luo	0.8	−0.1, 1.6	0.079
Male ($n = 592$)‡			
Intercept (BMI at 55 years)	22.0	21.4, 22.7	<0.001
Urban	5.4	4.0, 6.9	<0.001
Age (kg m^{-2}, 10 years)			
Urban	2.0	1.4, 2.5	<0.001
Rural	0.6	0.3, 0.9	<0.001
Ethnicity			
Kamba vs. Luo	−1.3	−2.0, −0.6	<0.001
Maasai vs. Luo	0.1	−0.6, 0.8	0.843
Waist–hip ratio			
Female ($n = 826$)§			
Intercept (waist–hip ratio at 55 years)	0.87	0.87; 0.88	<0.001
Urban	0.01	−0.004; 0.03	0.16
Age (cm, 10 years)			
Urban	0.03	0.03; 0.04	<0.001
Rural	0.02	0.01, 0.02	<0.001
Ethnicity			
Kamba vs. Luo	0.01	−0.003, 0.02	0.181
Maasai vs. Luo	−0.02	−0.03; −0.01	0.003
Male ($n = 592$)¶			
Intercept (waist–hip ratio at 55 years)	0.92	0.91; 0.93	<0.001
Urban	0.06	0.04, 0.08	<0.001
Age (cm, 10 years)			
Urban	0.05	0.04, 0.06	<0.001
Rural	0.02	0.02; 0.03	<0.001
Ethnicity			
Kamba vs. Luo	−0.01	−0.02; 0.003	0.136
Maasai vs. Luo	−0.001	−0.01; 0.01	0.784

Notes: *Urban residence was coded 1 if yes and 0 if no. Luo was used as reference category. Age was subtracted 55 years from each individual age to let the intercept reflect the mean of those at zero value of explanatory variables, i.e. Luo and rural dwellers aged 55 years.
†Interaction between urban residence and age; residual SD = 4.4.
‡Interaction between urban residence and age; residual SD = 3.5.
§Interaction between urban residence and age, residual SD = 0.05.
¶Interaction between urban residence and age, residual SD = 0.05.

was adjusted for. The effect of ethnicity was significant at $-1.3\,\text{kg m}^{-2}$ for the Kamba ($p < 0.001$), while there was no significant effect at $0.1\,\text{kg m}^{-2}$ for the Maasai ($p = 0.843$).

There was no age–urban interaction in AMA among females ($p = 0.806$), but a six-fold higher AMA in urban ($2.9\,\text{cm}^2$, $p < 0.001$) compared to rural males ($0.5\,\text{cm}^2$, $p = 0.166$)

Table VI. Predictors of arm fat area (cm^2) and arm muscle area (cm^2) stratified by gender with linear regression coefficients (*B*), 95% confidence intervals (CI) and *p*-values.*

	B (cm^2)	95% CI	*p*-value
Arm fat area			
Female ($n = 825$)†			
Intercept (arm fat area at 55 years)	25.5	23.0; 28.0	<0.001
Urban	19.9	15.2, 24.6	<0.001
Age (cm^2, 10 years)			
Urban	4.7	2.4, 7.0	<0.001
Rural	2.3	1.2, 3.4	<0.001
Ethnicity			
Kamba vs. Luo	−0.9	−3.3, 1.5	0.456
Maasai vs. Luo	4.7	1.9, 7.5	<0.001
Male ($n = 592$)‡			
Intercept (arm fat area at 55 years)	15.2	13.2; 17.1	<0.001
Urban	11.2	6.9, 15.5	<0.001
Age (cm^2, 10 years)			
Urban	4.1	2.5, 5.7	<0.001
Rural	2.2	1.3, 3.1	<0.001
Ethnicity			
Kamba vs. Luo	−2.2	−4.3, −0.1	0.041
Maasai vs. Luo	4.7	2.6, 6.8	<0.001
Arm muscle area			
Female ($n = 825$)§			
Intercept (arm muscle area at 55 years)	43.6	41.7; 45.4	<0.001
Urban	−5.9	−9.5, −2.4	<0.001
Age (cm^2, 10 years)	0.2	−1.7, 2.1	0.806
Ethnicity			
Kamba	5.0	3.2, 6.7	<0.001
Maasai	2.1	0.04, 4.2	0.046
Male ($n = 592$)¶			
Intercept (arm muscle area at 55 years)	48.3	46.7; 49.9	0.004
Urban	7.9	4.4, 11.4	<0.001
Age (cm^2, 10 years)			
Urban	2.9	1.6, 4.2	<0.001
Rural	0.5	−0.2, 1.2	0.166
Ethnicity			
Kamba	−5.4	−7.1, −3.7	<0.001
Maasai	−5.7	−7.4, −4.0	<0.001

Notes: *Urban residence was coded 1 if yes and 0 if no. Luo was used as reference category. Age was subtracted 55 years from each individual age to let the intercept reflect the mean of those at zero value of explanatory variables, i.e. Luo and rural dwellers aged 55 years.
†Interaction between urban residence and age, residual SD = 14.3.
‡Interaction between urban residence and age, residual SD = 10.5.
§Interaction between urban residence and age, residual SD = 10.8.
¶Interaction between urban residence and age, residual SD = 8.6.

per 10 years. Urban men had 7.9 cm^2 higher AMA while urban women had 5.9 cm^2 lower AMA. The Kamba and Maasai females had considerable higher AMA compared to the Luo ($p = 0.046$), while the opposite relationship was found among males ($p < 0.001$) (Table VI).

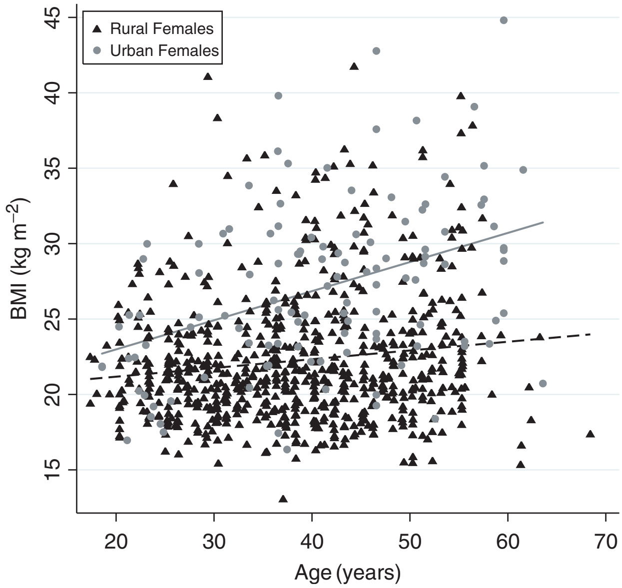

Figure 2. The relationship between age and body mass index (kg m^{-2}) in rural ($n = 717$) and urban ($n = 116$) female populations. Regression coefficient for rural females is 0.6 kg m^{-2}/10 years (95% CI: 0.3; 0.9), for urban females 1.9 kg m^{-2}/10 years (95% CI: 1.2; 2.6). Model R^2 is 0.17.

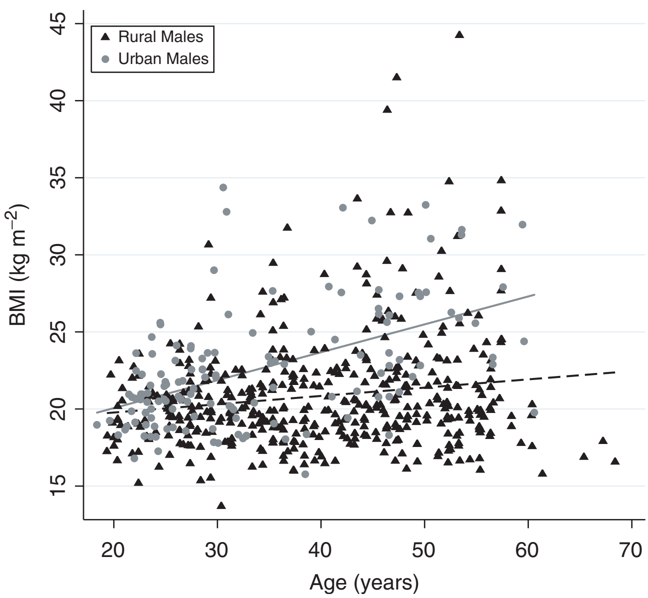

Figure 3. The relationship between age and body mass index (kg m^{-2}) in rural ($n = 461$) and urban ($n = 136$) male populations. Regression coefficient per 10 years for rural males is 0.6 kg m^{-2}/10 years (95% CI: 0.3; 0.9), for urban males 2.0 kg m^{-2}/10 years (95% CI: 1.4; 2.5). Model R^2 is 0.14.

Discussion

This is the first study using ultrasonographic scanning technique to discriminate between abdominal visceral fat and subcutaneous fat in African populations. We found higher values of both visceral and subcutaneous fat in the urban than in the rural population in both genders. Furthermore, men had higher visceral fat thickness, while women had higher subcutaneous fat thickness. This specific sex dimorphism has been shown in other studies including the ultrasonography scanning technique (Kim et al. 2004).

Among the ethnic groups, the male Maasai had the highest abdominal visceral thickness, in both absolute and relative terms, which may reflect a higher daily energy intake and/or a decline in physical activity. In previous investigations on male Maasai, their average daily caloric intake was estimated to be 3000 kcal (Biss et al. 1971), while their estimated fitness level was high across all age groups (55–59 ml O_2 kg^{-1} min^{-1}) until they reached their mid-40 s (Mann et al. 1965). The latter may be a social construct that could explain a higher abdominal visceral and subcutaneous fat accumulation in both genders with increasing age among the Maasai.

In contrast, the Luo had the lowest relative abdominal visceral fat thickness in both genders, but with increasing age the visceral fat thickness of the Luo females did not differ from those of the Kamba. As opposed to the Maasai who consume a diet high in fat (Nestel 1989), both the Luo and the Kamba consume a low-fat, high-carbohydrate diet (Ochieng 1979; van Steenbergen et al. 1984), which is substantially lower in daily energy intake among the males, but not in females. Thus, there seems to be a clearer picture of ethnic differences among males compared to females when it comes to lifestyle associations with visceral fat thickness.

By using ultrasonography and CT scanning, Ribeiro-Filho et al. (2003) showed that visceral obesity is associated with a higher amount of visceral-to-subcutaneous fat ratio in Brazilian women when defining visceral obesity as $CT > 130\,cm^2$. Visceral-obese and non-visceral-obese women in their study had mean visceral-to-subcutaneous fat ratio of 2.7 and 1.7, respectively. In our study population, all ethnic groups among both genders had much higher mean visceral-to-subcutaneous fat ratios ranging from 4.6 to 11.9 with the highest values in males. The visceral-obese group in the study of Ribeiro-Filho et al. (2003) had an ultrasonographic visceral fat cut-off value of 6.90 cm, and 0.97 for WHR. Since we did not perform CT scans, we cannot make a similar cut-off value of ultrasonographic measured visceral fat thickness, nor elevated WHR. But the striking differences in visceral-to-subcutaneous fat ratio emphasized above suggest ethnic differences even though ethnicity in the Brazilian study population was not defined. Nevertheless, in order to establish cut-offs for defining elevated visceral fat levels as well as diagnostic cut-offs for visceral obesity measured by ultrasonography that would indicate increased risk of cardiovascular and metabolic disease, prospective studies are needed.

In our study, overweight and obesity was high in Kenyans based on BMI, but substantially higher in urban compared to rural populations among both genders. Furthermore, the difference in overweight between the genders was very pronounced, with a much higher prevalence among women compared to men in rural (19.5% vs. 10.0%) as well as urban (60.3% vs. 22.6%) areas with even higher ratios in obesity differences among the genders. When controlling for age and ethnicity, BMI in urban compared to rural populations was substantially higher in both genders as well, and the difference was more pronounced with increasing age as illustrated in Figures 2 and 3. These findings are in line with previous observations from sub-Saharan Africa demonstrating higher BMI in urban compared to rural areas, and higher BMI in females as compared to males (Mollentze et al. 1995;

Msamati and Igbigbi 2000; Njelekela et al. 2002; Amoah 2003; Pasquet et al. 2003; Sobngwi et al. 2004; Fezeu et al. 2005; Kamadjeu et al. 2006; Siervo et al. 2006).

However, our findings suggest that relying on BMI alone for an assessment of overweight and obesity due to fat accumulation is insufficient. First of all, the sex dimorphism in abdominal visceral and subcutaneous fat may be an important limitation of BMI when it comes to interpreting the relationship between obesity and metabolic disorders. Further, prevalence of central obesity expressed as WC also showed a marked gender difference, with the highest prevalence among urban females; a gender and residential distribution which was similar to that of BMI. However, the lack of discrimination between fat mass and lean body mass in BMI measurements is evident in our study. We found a higher AMA in the urban compared to the rural male population, but the opposite result among the females. Two scenarios are possible to explain this discrepancy, and they may not be mutually exclusive. Either the more physically fit males may have migrated, or they may have been engaged in more physically demanding jobs compared to their rural counterparts. For the urban females, they may have been engaged in less physically demanding work compared to the rural females. Thus, the interaction of biological and cultural factors is a plausible explanation for this gender and rural–urban difference in lean body mass. Further, AFA was higher in the urban population in both genders. Based on the AMA and AFA measurements it becomes evident that BMI must be interpreted with caution.

This study also found a relatively high prevalence of underweight in both genders, primarily in the rural areas (16.6% and 23.4% in females and males, respectively), which is similar to results from a study conducted in Congo-Brazzaville, that showed an underweight prevalence of 19.5% in women (Gartner et al. 2000). Low underweight prevalence in an urban African population has been shown in Cameroon (Pasquet et al. 2003), but we found a relatively high prevalence of underweight of 5.2% and 11.7% in urban females and males, respectively, showing that Kenya has to deal with the double burden of malnutrition in the future, like several other countries in sub-Saharan Africa (Steyn et al. 1998; Gartner et al. 2000; Msamati and Igbigbi 2000).

When we conducted our study among the Maasai in the months of October–November, approximately 4 months had passed since the end of the long wet season and the short wet season had began during the study period. The fat content of milk from cattle has been shown to be highest during the short rains among the Nilotic Turkana (Galvin and Waweru 1987). When we conducted our study among the Luo and Kamba, they had recently completed the harvest of maize. Thus, the study as a whole was carried out at a time when food availability was expected to be adequate in all three rural populations. However, it is of note that periods of drought had been a problem among the Kamba in Kitui district for 7 years at the time of the study, which could have affected the food availability and thereby their body composition. Further, the dietary intake of the urban population is not dependent on seasonal variability to the same extent as the rural population, and the timing of the study is therefore of less importance in this population.

A limitation of this study is the potential selection bias of the participants, which may have affected prevalence calculations, and to a lesser extent associations between anthropometric parameters. Another limitation is the small sample size of the urban Maasai (seven males and no females), especially since this group exhibited the highest accumulation of fat as shown in the multivariate analyses. This discrepancy between rural–urban distributions of participants and the ethnic groups may impact on the obesity prevalence in the urban population and the interpretation of the multivariate analyses. Further, in order to overcome the uneven age distribution between the ethnic groups and rural vs. urban populations, the age of 55 years as a point of reference was chosen. Importantly, this relatively advanced age in a Kenyan context also made it possible to make assumptions about age-related fat accumulation in this cross-sectional study.

As a final note on limitations of the study, the fact that we did not collect data on HIV/AIDS could confound body composition parameters, since this infectious disease is associated with wasting as well as lipodystrophy (Karmon et al. 2005).

Based on the fat accumulation among the ethnic groups of this study, and especially central obesity, the Maasai seem to be at the highest risk of cardiovascular disease. However, in spite of historical evidence that the Maasai have a higher fat accumulation compared to other ethnic groups of Kenya (Jansen and Horelli 1984), they seem not to be prone to cardiovascular disease (Mann et al. 1964). Whether this will change, or the Maasai are protected by a favourable genetic make-up is subject to future investigations.

In summary, we found a higher level of both abdominal visceral and subcutaneous fat in the urban compared to the rural population among both genders, but cut-off values need to be established for high-risk visceral fat thickness. For a given abdominal fat accumulation, females had a higher subcutaneous fat mass compared to males who had more visceral fat for a given accumulation of abdominal fat. We also found higher levels of obesity expressed as BMI and WC in urban compared to rural populations, and higher levels in women compared to men. Looking at all fat variables in combination, the Maasai had the highest accumulation in both genders. The higher obesity prevalence with urbanization and the marked gender and ethnic differences in obesity patterns and their relationship to health risks need to be further explored in African populations.

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