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RESEARCH PAPER

Rural–urban variations in age at menarche, adult height, leg-length and abdominal adiposity in black South African women in transitioning South Africa

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[a]MRC/WITS Developmental Pathways for Health Research Unit, Department of Paediatrics, School of Clinical Medicine, Faculty of Health Sciences, University of Witwatersrand, Johannesburg, South Africa; [b]Human and Social Development Research Programme, Human Sciences Research Council, Pretoria, South Africa; [c]MRC/Wits Rural Public Health and Health Transitions Research Unit, School of Public Health, Faculty of Health Sciences, University of the Witwatersrand, Johannesburg Parktown, South Africa; [d]INDEPTH Network, Accra, Ghana; [e]Umeå Centre for Global Health Research, Umeå University, Umeå, Sweden; [f]School of Demography, The Australian National University, Acton, Australia; [g]Department of Paediatrics, University of Cambridge, Cambridge, UK

ABSTRACT

Background: The pre-pubertal socioeconomic environment may be an important determinant of age at menarche, adult height, body proportions and adiposity: traits closely linked to adolescent and adult health.

Aims: This study explored differences in age at menarche, adult height, relative leg-length and waist circumference between rural and urban black South African young adult women, who are at different stages of the nutrition and epidemiologic transitions.

Subjects and methods: We compared 18–23 year-old black South African women, 482 urban-dwelling from Soweto and 509 from the rural Mpumalanga province. Age at menarche, obstetric history and household socio-demographic and economic information were recorded using interview-administered questionnaires. Height, sitting-height, hip and waist circumference were measured using standardised techniques.

Results: Urban and rural black South African women differed in their age at menarche (at ages 12.7 and 14.5 years, respectively). In urban women, a one-year increase in age at menarche was associated with a 0.65 cm and 0.16% increase in height and relative leg-length ratio, respectively. In both settings, earlier age at menarche and shorter relative leg-length were independently associated with an increase in waist circumference.

Conclusions: In black South African women, the earlier onset of puberty, and consequently an earlier growth cessation process, may lead to central fat mass accumulation in adulthood.

Introduction

Age at menarche and adult stature are very plastic phenotypic traits responsive to environmental exposures from intra-uterine life (Dubois et al., 2012; Jelenkovic et al., 2016; Karapanou & Papadimitriou, 2010; Yermachenko & Dvornyk, 2014). Downward secular trends in age at menarche have been observed in several populations and associated with economic development and the improvement in nutrition and health in this last century (Karapanou & Papadimitriou, 2010; Yermachenko & Dvornyk, 2014). Adult stature, its determinants and consequences, has also been the subject of myriad studies in different populations which reported a secular increase in height in populations, though limited in sub-Saharan Africa, as living conditions improved this last century (Cole, 2000; Malina, 2004; NCD Risk Factor Collaboration, 2016).

Age at menarche has been found to be a strong predictor of adult height (McIntyre & Kacerosky, 2011) and leg-length

(McIntyre, 2011; Onland-Moret et al., 2005; Osuch et al., 2010; Schooling et al., 2010). Physiologically, the association between age at menarche and adult stature and body proportions might be driven by the effect of oestrogen on bone growth, modelling and remodelling (Eastell, 2005). When oestrogen increases during the pubertal transition it antagonises growth hormones (GH and IGF-1), which slows linear growth, accelerates the closure and fusion of the epiphyseal plates, and marks the end of the linear growth process (Eastell, 2005). The direction of the association between age at menarche and adult height may differ according to the population considered (McIntyre & Kacerosky, 2011). In developed countries, later menarche has been associated with greater adult height, while in small-scale societies (populations living in subsistence-based economy, unplanned fertility and with poor access to healthcare) delayed puberty has been associated with shorter final stature (McIntyre & Kacerosky, 2011). Moreover, earlier age at menarche, shorter

adult stature and leg-length have been associated with higher levels of adiposity, in both the trunk and abdominal region, and with cardio-metabolic diseases (Frisancho, 2007; Janghorbani et al., 2014; Prentice & Viner, 2013).

Since 1990, South Africa has experienced remarkable political, social, demographic and economic transitions (Collinson et al., 2007; Inman & Rubinfeld, 2013). Secular trends towards a decrease in age at menarche since the 1940s have been described in black South African women (Cameron & Wright, 1990). Twenty years ago, the latest study found that urban black South African girls had an earlier age at menarche in comparison to their rural peers (Cameron & Wright, 1990; Cameron et al., 1991). In addition, the ongoing nutrition transition (Norris et al., 2014; Vorster et al., 2011) has been associated with high rates of overweight or obesity in all age groups, particularly in women of reproductive age (47% of the 19–25 years old), and in women living in urban areas in comparison to rural areas (Cameron et al., 1991; Jones et al., 2009a; Shisana et al., 2014). In urban areas, a larger body size (height and body mass index) during childhood was associated with earlier age at menarche (Lundeen et al., 2016a) and risks of overweight and obesity in young adulthood (Stein et al., 2016). However despite the transitions, women's adult height has only modestly changed in the last 20 years, with no marked difference between rural and urban areas (Department of Health, SA MRC, 2002, 2007; Shisana et al., 2014). In South Africa, factors associated with adult body height such as under-nutrition and infectious diseases (Karapanou & Papadimitriou, 2010; McDonald et al., 2016; Yermachenko & Dvornyk, 2014) remain, and at particularly higher rates in rural areas (Gomez-Olive et al., 2013; Kimani-Murage, 2013; Said-Mohamed et al., 2015).

We hypothesise that urban–rural disparities in economic development, living conditions and in the epidemiology of under-nutrition, infections and obesity may translate into differences in pubertal timing, adult height and body composition in black South African women. To our knowledge, there is as yet no study that compares the associations between age at menarche and adult body size, proportions and composition in rural and urban black South African women. The objectives of this article are to compare rural and urban young adult black South African women living in South Africa: (i) by their age at menarche and (ii) by the relationships between age at menarche, body stature and proportions and abdominal fat mass.

Methods

Study design and setting

This cross-sectional study comprises young adult black South African women living in South Africa in the rural Agincourt Health and Socio-demographic Surveillance System (Agincourt HDSS) research site (Bushbuckridge, Mpumalanga) and in urban Greater Soweto (Johannesburg, Gauteng). In both sites, populations are mainly black South African (Stats SA, 2012). The rural site consists of 31 villages (over 110,000 inhabitants) that stretch over an area of 475 km². It is characterised by poor living conditions (including poor road

infrastructure, no piped water and rudimentary sanitation and difficult access to health facilities). The ongoing epidemiological transition is evident by the coexistence of a high prevalence of under-nutrition in children and adult overweight/obesity as well as a high prevalence of HIV/AIDS and an increasing prevalence of cardiovascular and metabolic diseases (Clark et al., 2015; Gomez-Olive et al., 2013; Kahn et al., 2012; Kimani-Murage, 2013; Maredza et al., 2016). Urban Soweto (200 km²) is home to over 1,271,628 inhabitants (Stats SA, 2012). Although Soweto has a high population density, the majority of Sowetan households have good access to piped water, sanitation facilities and healthcare. Like other urban South African areas, Soweto is characterised by the high prevalence of overweight/obesity and associated metabolic and cardiovascular diseases, while HIV/AIDS and under-nutrition persist (Lundeen et al., 2016b; Shisana et al., 2014; Stats SA, 2016a; Tibazarwa et al., 2009). For this study, data were collected between December 2012 and July 2013 in Agincourt, and March 2012 to December 2014 in Soweto.

Participants

In the rural site, 509 black South African female participants aged between 18–21 years old were randomly selected from the Agincourt HDSS site census. In the urban site, 482 black South African women aged between 21–23 years old were randomly selected from the Birth-to-Twenty plus (BT20+) cohort study (protocol described in Richter et al., 2007 and Pradeilles et al., 2014), who were participating in the Young Adult Survey. All participants provided written consent to participate in the study and were not mentally or physically disabled. The study protocols were approved by the Human Research Ethics Committee of the University of the Witwatersrand (Clearance certificates M120138 for the Ntshembo-Hope Cross-sectional Survey and M111182 for the BT20 + survey).

Variables

The same questionnaires and biometrical measurements were utilised in the rural and urban areas. The research teams were centrally trained to harmonise the data collection across the two sites.

Age at menarche and pregnancy

In the rural area, participants were asked to recall their age at first menstruation via an interview-administered questionnaire. In the BT20 + longitudinal study, participants were asked their age at first menstruation annually on 6 occasions, commencing when the participants were 9 years of age (Jones et al., 2009b). For each site, we used the mode value to categorise the age at menarche as: earlier age at menarche (age at menarche < mode), medium age at menarche (age at menarche = mode) or later age at menarche (age at menarche > mode). We chose the mode value because it is the age at which most of the individuals in the population reached the age at menarche and as such, it can serve as a

reference for the population. We assessed participants' obstetric history, as well as previous and current pregnancy, through an interview-based questionnaire.

Height, sitting-height, waist and hip circumferences

At both sites, anthropometric measurements were performed following standardised procedures (Cameron, 1984; Lohman et al., 1988). Standing height was measured to the nearest millimetre using a calibrated Holtain Stadiometer® (Crymych, UK). To measure sitting height, participants were seated in a chair with a solid base. We measured the height from the vertex of the head and the sitting height was then derived by subtracting chair height from the obtained value. Relative leg-length ratio was calculated as the (standing height – sitting height)*100/standing height (Bogin & Varela-Silva, 2010). Weight was measured to the nearest 0.1 kg in light clothing using the Tanita model TBF-410 (Arlinghton Heights; USA) digital scale procedures (Cameron, 1984; Lohman et al., 1988). Waist and hip circumferences were measured at the level of the umbilicus and at the maximum circumference of the buttock, respectively, using a non-stretchable fibreglass insertion tape.

Socio-demographics

Participants' age, education and socio-economic status were obtained through an interviewer-administered questionnaire. A socio-economic status index was generated by summing the number of assets owned in the household from the following options: TV, car, washing machine, fridge, phone, radio, microwave, cell phone, DVD/Video, DSTV (cable channel), computer, internet access and medical aid (Kagura et al., 2016).

Statistical analysis

All women who reported to be pregnant or thought that they may be pregnant ($n = 51$) at the time of data collection were excluded from the analyses. All statistical analyses were done using STATA 13 (StataCorp. 2013; Stata Statistical Software: Release 13; College Station, TX: StataCorp LP) and significance levels were considered at p-values <.05.

Student's unpaired t-test, Chi-squared test and analysis of variance were performed to compare rural and urban characteristics. When ANOVA analyses showed that there was a statistical difference between groups, Bonferroni post-hoc analysis was performed to identify which groups differed.

A first series of multivariate linear regression analysis was done to assess whether age at menarche was associated with height and relative leg-length in urban and rural young adult women. Two models and four linear regression analyses were run for each site, as there were two independent and two dependent variables (respectively, continuous or categorical menarche variables and adult height or adult relative leg length). In Model 1, adult height or adult relative leg length were regressed on age at menarche variables. Model 2 was Model 1 adjusted for age, socio-economic status and education. All the regression models with relative leg-length

as the dependent variable were adjusted for hip circumference, since gluteo-femoral fat mass can increase the sitting height measurements, particularly in overweight populations (Bogin & Varela-Silva, 2008). Covariates included in Model 2 were identified from the literature on the factors associated with age at menarche (Karapanou & Papadimitriou, 2010; Yermachenko & Dvornyk, 2014).

A second series of multivariate linear regression analyses then assessed whether age at menarche and height or leg-length were independently associated with central adiposity as measured by waist circumference in urban and in rural young adult women. Two models and four linear regression analyses were run for each site, as there were four independent variables (continuous or categorical menarche variables and adult height or adult relative leg length). In Model 1, waist circumference was regressed on age at menarche variables (continuous or categorical) and adult height or adult relative leg length. In Model 2, all the regression analyses were then re-run adjusted for socioeconomic status, age, education and previous pregnancy as covariates. Covariates included in Model 2 were previously found to be associated with waist circumference (Cois & Day 2015; Kimani-Murage et al. 2011).

Results

Participants' characteristics

Women in the urban sample at the time of assessment were significantly older (mean difference of 1 year and 5 months) than the women in the rural sample (Table 1). Urban women had their menarche on average 1.8 years earlier than the rural women and were on average 1.68 cm shorter with a smaller relative leg-length ratio than rural women. Rural and urban women did not differ in their waist circumference. Figure 1 presents the rural–urban women anthropometric differences on a silhouette.

Differences were noted between the two settings in relation to pregnancy, where urban women were less likely to have been pregnant previously ($p < .01$) in comparison to rural women. Educational attainment was higher among urban women with 51% having completed post-high school studies compared to 19% of the rural sample ($p < .01$).

Associations between age at menarche, height and relative leg-length

Urban women with earlier menarche were 2.4 cm shorter than those with later menarche ($p < .01$) and had smaller relative leg-length in comparison to medium ($p < .05$) or later menarche women ($p < .001$) in post-hoc analysis (Table 1). Rural women had similar heights and relative leg-lengths across the categories of age at menarche.

We then explored whether age at menarche predicted adult height and relative leg-length in urban and rural settings adjusting for socio-economic status, age and education (Table 2). In urban women, age at menarche was predictive of both their adult height and relative leg-length. For instance, a one-year delay in age at menarche translated into a 0.65 cm increase in adult height and a 0.16% increase in

Table 1. Participants' anthropometrics, socio-demographic and socio-economic characteristics by study site.

	Rural (n = 509) Mean (SD) or %	Urban (n = 482) Mean (SD) or %	p values
Ethnicity (%)			
Black South African	100	100	
Age (years)	21.3 (1.3)	22.7 (0.4)	***
Age at menarche (years)	14.5 (1.4)	12.7 (1.2)	***
Mode	14	13	
Earlier menarche (%)	21	43	***
Medium menarche (%)	34	34	
Later menarche (%)	45	23	
Height (cm)	161.5 (6.7)	159.8 (6.2)	***
Height if earlier menarche (cm)	160.9 (6.4)	158.9 (6.3)	ns (Rural) **(Urban)
Height if medium menarche (cm)	161.8 (6.9)	160.0 (5.8)	
Height if later menarche (cm)	161.5 (6.6)	161.3 (6.5)	
Relative leg length (% of standing height)	49.6 (2.4)	49.1 (1.5)	***
Leg length ratio if earlier menarche	49.3 (2.4)	48.8 (1.4)	ns (Rural) ***(Urban)
Leg length ratio if medium menarche	49.7 (2.2)	49.2 (1.4)	
Leg length ratio if later menarche	49.6 (2.5)	49.5 (1.5)	
Waist circumference (cm)	81.0 (11.4)	80.2 (12.6)	ns
Waist circumference if earlier menarche (cm)	83.7 (11.1)	82.7 (13.2)	*(Rural) ***(Urban)
Waist circumference if medium menarche (cm)	80.3 (11.6)	79.9 (12.3)	
Waist circumference if later menarche (cm)	80.3 (11.3)	75.9 (10.9)	
SES (Sum of assets)	5.5 (1.9)	8.8 (2.4)	***
Pregnancy before interview (%)			**
Yes	65	54	
No	35	46	
Highest education level (%)			***
University/College	19	51	
Graduated from high school	38	16	
High school or primary school	43	33	

Analyses are Chi-square and Analysis of Variance. Significance: ns, not significant; $*p < .05$; $**p < .01$, $***p < .001$.
SES: socio-economic status index; Earlier menarche: age at menarche < Mode; Normal menarche: age at menarche = Mode; Later Menarche: age at menarche > Mode.

RURAL 161.5cm

URBAN 159.8cm

AGE AT MENARCHE: 14.5yrs

81.35cm 81.38cm

81.0cm 80.2cm

101.7cm 103.9cm
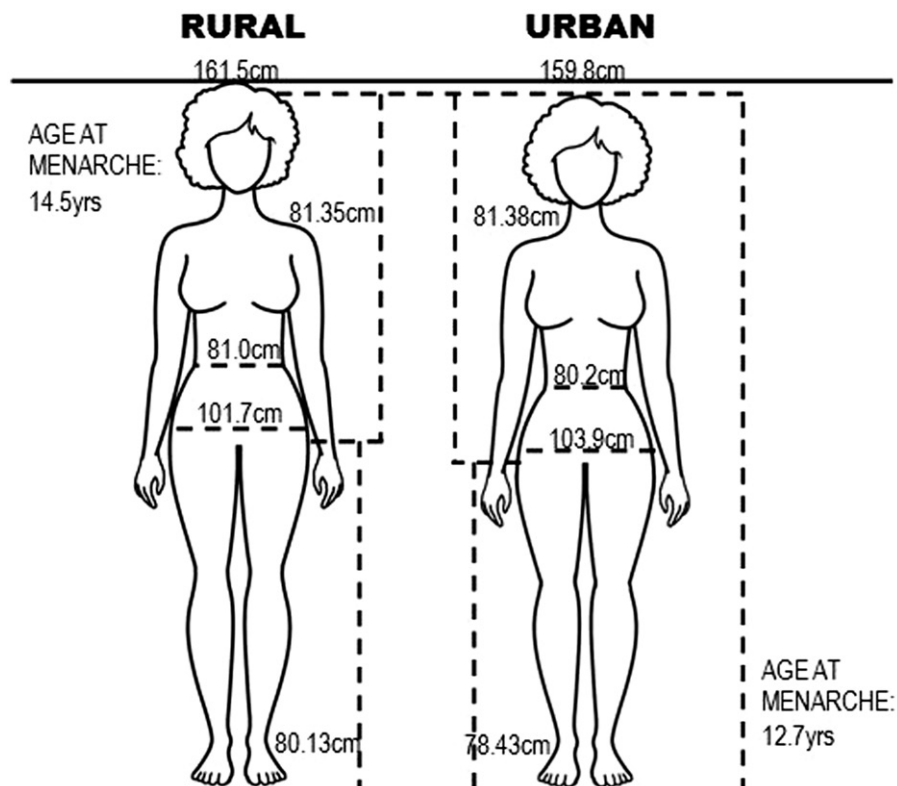
80.13cm 78.43cm

AGE AT MENARCHE: 12.7yrs

Figure 1. Anthropometric characteristics and age at menarche in rural and urban young adult black South African women.

Table 2. Association between height, relative leg length and age at menarche by study site.

Study site and outcome	Model 1 β (95% CI)	Model 2 β (95% CI)
Urban		
Height (cm)		
Age at menarche	0.71 (0.27–1.15)**	0.65 (0.20–1.10)**
Medium menarche	Reference	Reference
Earlier menarche	−1.05 (−2.32–0.22)	−1.06 (−2.35–0.23)
Later menarche	1.26 (−0.24–2.76)	1.13 (−0.39–2.65)
Relative leg length (% of adult height)		
Age at menarche	0.17 (0.07–0.26)***	0.16 (0.06–0.26)**
Medium menarche	Reference	Reference
Earlier menarche	−0.30 (−0.58 to −0.02)*	−0.26 (−0.54–0.02)
Later menarche	0.16 (−0.17–0.49)	0.17 (−0.17–0.50)
Rural		
Height (cm)		
Age at menarche	0.13 (−0.31–0.58)	0.36 (−0.15–0.87)
Medium menarche	Reference	Reference
Earlier menarche	−0.94 (−2.57–0.70)	−1.66 (−3.50–0.16)
Later menarche	−0.31 (−1.66–1.04)	−0.22 (−1.74–1.30)
Relative leg length (% of adult height)		
Age at menarche	−0.01 (−0.17–0.15)	0.02 (−0.17–0.21)
Medium menarche	Reference	Reference
Earlier menarche	−0.36 (−0.95–0.23)	−0.52 (−1.16–0.13)
Later menarche	−0.14 (−0.63–0.34)	−0.27 (−0.80–0.27)

Analyses are multivariate linear regressions. Model 1 are unadjusted when height is the outcome and adjusted for hip circumference when relative leg length is the outcome, Model 2 are adjusted for age, socio-economic status, education (and hip circumference when relative leg length is the outcome). Significance: $*p < .05$; $**p < .01$, $***p < .001$.

relative leg-length in the adjusted models. In rural women, we did not observe significant associations between the timing of menarche and adult height or relative leg-length.

Associations between waist circumference, age at menarche, height and relative leg-length

Urban women with later menarche had the smallest waist circumference (−6.8 cm vs earlier menarche, $p < .001$, and −4 cm vs medium menarche, $p < .05$, in post-hoc analysis) (Table 1). Among rural women, differences were in line with the findings in urban women, but associations were weaker (Table 1).

We then explored whether age at menarche and adult height or leg-length independently predicted waist circumference in rural and urban young adult women (Table 3). In urban women, age at menarche and height or relative leg-length were independently associated with waist circumference. In the adjusted model, when height was held constant, a one year increase in age at menarche was associated with a 2.41 cm decrease in waist circumference, and having a later age at menarche in comparison to having a medium age at menarche was associated with a reduction of 3.97 cm in waist circumference. Similar results were found when relative leg-length was held constant. Furthermore, having an earlier age at menarche in comparison to having a medium age at menarche was associated with an increase in waist circumference of 3.59 cm and 2.60 cm, respectively, when height and leg-length were held constant. In adjusted models, on one hand we found that a 1 cm increase in height was associated with a 0.31 cm increase in waist circumference when age or timing of menarche was held constant. On the other hand, we found that a percentage increase in relative leg-length was associated with a reduction by 1.89 cm and 1.92 cm in waist circumference.

In rural women, the associations between waist circumference and age at menarche and adult height or relative leg-length were similar but weaker than in urban women (Table 3). In addition, in adjusted models, only age at menarche and having an earlier menarche, but not height, were significantly and independently associated with waist circumference. Only relative leg-length, but not age or timing of menarche, was consistently significantly and independently associated with waist circumference.

Discussion

The objectives of this study were to compare among black South African women living in urban and rural areas in South Africa their age at menarche and its association with adult height and relative leg-length. Furthermore, this study aimed to assess the relationship between waist circumference and age at menarche, adult height and relative leg-length. We found differences between urban and rural women. Urban girls had an earlier menarche and their timing of menarche predicted adult height and leg-length, an association not found in rural women. In addition, timing of menarche, height and relative leg length independently predicted waist circumference in urban women, but in rural women only earlier menarche and relative leg-length did. Finally, later age at menarche was independently associated with a decrease in waist circumference in urban women.

Age at menarche and its association with adult height and leg-length in rural and urban women

Menarche occurs earlier in urban compared to rural women

This study presents the most recent comparative data on age at menarche in contemporary urban and rural black South

Table 3. Multivariate associations between waist circumference and age at menarche, height and relative leg length by study site.

Study site and outcome	Model 1 β (95% CI)	Model 2 β (95% CI)
Urban		
Waist circumference		
Age at menarche	−2.33 (−3.24 to −1.43)***	−2.41 (−3.31 to −1.51)***
Height (cm)	0.31 (0.13–0.51)**	0.31 (0.12–0.50)**
Waist circumference		
Medium menarche	Reference	Reference
Earlier menarche	3.38 (0.76–5.99)*	3.59 (0.98–6.19)**
Later menarche	−4.15 (−7.21 to −1.08)**	−3.97 (−7.01 to −0.92)*
Height (cm)	0.32 (0.14–0.51)**	0.31 (0.13–0.50)**
Waist circumference		
Age at menarche	−1.62 (−2.53 to −0.71)**	−1.70 (−2.61 to −0.80)***
Relative leg length (% of adult height)	−1.88 (−2.68 to −1.08)***	−1.89 (−2.69 to −1.10)***
Waist circumference		
Medium menarche	Reference	Reference
Earlier menarche	2.38 (−0.22–4.97)	2.60 (0.018–5.17)*
Later menarche	−2.96 (−6.00 to −0.06)	−2.78 (−5.79–0.22)
Relative leg length (% of adult height))	−1.90 (−2.70 to −1.11)***	−1.92 (−2.71 to −1.13)***
Rural		
Waist circumference		
Age at menarche	−1.03 (−1.79 to −0.24)**	−0.91 (−1.80 to −0.02)*
Height (cm)	0.13 (−0.03–0.29)	0.12 (−0.06–0.30)
Waist circumference		
Medium menarche	Reference	Reference
Earlier menarche	3.75 (0.87–6.64)*	3.43 (0.14–6.73)*
Later menarche	0.26 (−2.15–2.66)	0.20 (−2.54–2.93)
Height (cm)	0.17 (0.01–0.32)*	0.15 (−0.03–0.32)
Waist circumference		
Age at menarche	−1.00 (−1.76 to −0.24)*	−0.81 (−1.70–0.07)
Relative leg length (% of adult height)	−0.63 (−1.07 to −0.18)**	−0.71 (−1.20 to −0.21)**
Waist circumference		
Medium menarche	Reference	Reference
Earlier menarche	3.28 (0.39–6.17)*	2.62 (−0.66–5.89)
Later menarche	0.06 (−2.34–2.47)	−0.12 (−2.86–2.61)
Relative leg length (% of adult height)	−0.55 (−0.99 to −0.12)*	−0.70 (−1.20 to −0.20)**

Analyses are multivariate linear regressions. Model 1 are unadjusted, Model 2 are adjusted for age, socio-economic status, education and previous pregnancy. Significance: *$p < .05$; **$p < .01$, ***$p < .001$.

African women (Cameron & Wright, 1990; Cameron et al., 1991). Our results show that urban black South African women reach menarche 1.8 years earlier than rural black South African women. The previous study in 1988–1989 compared black South African women in Soweto vs women in Ubombo (rural KwaZulu Natal) and found that the age at menarche of urban women was 0.8 years earlier than that of their rural counterparts (Cameron & Wright, 1990; Cameron et al., 1991). Although the methods used to determine the age at menarche and the geographical areas investigated differ, comparing these results with our results suggests that in the last two decades the urban–rural difference in menarcheal age in black South African women in South Africa has increased by one year. This is mainly attributed to the decline in urban age at menarche between 13.2 years old in 1988 (Cameron & Wright, 1990) and 12.7 years old in the present study, while in rural areas the decline is less marked, i.e. between 14.6 years old in 1988 (Cameron & Wright, 1990) and 14.5 years old in the present study. In fact, in the last 50 years, downward secular trends in age at menarche in black South African women in South Africa have been described; with a pronounced rapid decline in urban women in comparison to their rural peers (Cameron et al., 1991; Jones et al., 2009a).

Similar urban–rural differences in age at menarche were also seen in LMICs populations experiencing similar transitions as South Africa (Ameade & Garti, 2016; Maddah, 2009;

Pasquet et al., 1999; Ray et al., 2010). For a long time, a population's downward trend in the age at menarche has been interpreted as a marker of the improvement of living conditions, health and socio-economic inequalities (Karapanou & Papadimitriou, 2010; Yermachenko & Dvornyk, 2014). Urban–rural changes in age at menarche in black South African women could result from changes in lifestyle and eating habits, and the political, demographic, economic and epidemiologic transitions happening since 1990 (more rapidly in urban areas in comparison to rural areas) (Clark et al., 2015; Collinson et al., 2007; Gomez-Olive et al., 2013; Inman & Rubinfeld, 2013; Kahn et al., 2012; Kimani-Murage, 2013; Maredza et al., 2016; Nnyepi et al., 2015; Steyn et al., 2012).

Nevertheless, in these last two decades, studies have found that earlier menarche is also associated with harmful health indices in pre-natal (including maternal excess weight gain during pregnancy, prematurity, intra-uterine growth restriction) and pre-pubertal periods (including excess fat mass and rapid weight gain, psychosocial stress and exposures to environmental hazards during infancy and childhood) (Yermachenko & Dvornyk, 2014). Between 1994 and 2004, corresponding to the pre-pubertal period of the participants of this study, the prevalence of stunting (a chronic form of under-nutrition) in girls of 8–11 years of age dropped from 21.3% to 4.3% but the prevalence of overweight in the same age group increased from 1.4% to 16.5% in South

Africa (Armstrong et al., 2011). Urban children were more affected by overweight/obesity and rural children by under-nutrition (Labadarios et al., 2005). Childhood overweight and obesity and rapid weight gain were shown to be predictors of earlier menarche (Ong et al., 2009). In the BT20 cohort, from which we selected our urban participants, (1) a transient catch-up in weight between birth and 1 year of age was associated with earlier menarche and (2) taller girls at 5 years of age and girls who had higher body mass index by the age of 5 years were more likely to have a faster pubertal transition (Lundeen et al., 2016b; Salgin et al., 2005). Thus, earlier puberty in urban areas could result from higher rates of overweight/obesity in childhood, while later puberty in rural areas could be associated with the higher rates of under-nutrition (Belachew et al., 2011; Leenstra et al., 2005).

Rural–urban differences in the association between age at menarche and adult height and leg-length

In comparison to their urban peers, we found that rural women were slightly taller with greater leg-length. The small rural–urban differences in adult stature are in line with the small differences reported in recent surveys of women living in the Soweto and the Agincourt HDSS site (unpublished data from The Human Heredity and Health in Africa Initiative). In addition, we found that in the black South African women from Soweto, the later the age at menarche the greater the adult height and relative leg-length, which is in accordance with the results found using all participants of the BT20 cohort prospective study (Stein et al., 2016). These results suggest that, in black South African women, earlier age at menarche predicts shorter adult stature and that the reduction in leg-length may account for the reduction in adult stature. Leg-length has been suggested to mediate the positive association between age at menarche and adult height (McIntyre & Kacerosky, 2011; Onland-Moret et al., 2005; Osuch et al., 2010; Schooling et al., 2010). In fact, the growth rate of legs from birth to pre-puberty is faster than any other part of the body and contributes most to variability in stature (Bogin & Varela-Silva, 2010). Accordingly, we suggest that an earlier pubertal maturation in an urban area will limit linear growth earlier resulting in shorter adults with shorter leg-length, while a later pubertal onset in rural women may allow a longer period of linear growth and in particular of leg-length. Our findings may suggest that, in urban black South African women, the fast transition in the pre-pubertal period from living in poor environments to relatively better conditions (favourable to the increase in the prevalence of overweight and obesity as previously described) may have led to earlier menarche and shorter adult stature (McIntyre, 2011).

The positive association between age at menarche and height found in urban black South African women is consistent with that found in 'industrialized societies' in McIntyre and Kacerosky's (2011) meta-analysis. In contrast, rural black South African women do not have an association between age at menarche and adult stature and body proportions. Using a life history theory approach, McIntyre and Kacerosky (2011) suggest that as the conditions of growth improve, the direction of the association between age at menarche changes from being negative to positive. Our results could illustrate McIntyre and Kacerosky's (2011) hypothesis and their predictions in that when mid-level industrial populations transition from an adverse to a better environment, the association between age at menarche and adult stature would be weak. While the transition to a democratic South Africa in the 1990s has officially abolished social stratification in the entire country, South Africa has remained one of the most economically unequal countries, with slower economic and demographic transitions in rural areas (Leibbrandt et al., 2010). Living in Soweto in the early 1990s, when urban black South African women of this study were in their infancy to early childhood periods, was associated with deprived conditions (Mears, 1997). Since the mid-1990s, Soweto has benefitted from renovation policies and from being in the industrial base and the wealthiest province of South Africa, which offered more economic opportunities (Beall et al., 2002; Mears, 1997; Turok, 2012). In contrast, Mpumalanga province, where the Agincourt HDSS rural site is situated, is one of the poorest provinces of the country (Stats SA, 2016a,b). Surveys in the Agincourt HDSS site during the period between 1990 and 2003 found an increase in adult and infant mortality (mostly related to the HIV/AIDS epidemic), a reduction in fertility and an increase in out-migration of black South African women to the cities (Houle et al., 2014, 2016; Saloojee et al., 2007; Sartorius et al., 2010). We argue that the high extrinsic adult mortality in the rural area might be offset by the persistence of the high level of infant/childhood under-nutrition and mortality resulting in later age at menarche and no association between age at menarche and adult stature/body proportions (Day & Rowe, 2002; McIntyre & Kacerosky, 2011). A recent study in Indonesia also found no to a weak relationship between age at menarche and height (Sohn, 2014). Sohn (2014) suggested that although Indonesia has experienced a rapid industrialisation since the 1960s, populations are still growing in poor conditions (Sohn, 2014).

In summary, we hypothesise that the urban phenotype [earlier puberty—adult short leg-length and stature] may result from higher rates of overweight/obesity in childhood following early life under-nutrition, while the rural phenotype [later puberty— taller adult leg-length and stature] may be associated with the persistence of high rates of pre-pubertal under-nutrition (Belachew et al., 2011).

Adult abdominal adiposity and age at menarche, adult height and body proportions

In both urban and rural areas an earlier menarche is associated with a higher abdominal adiposity level in young adulthood. Reciprocally, we found that in urban black South African women, later age at menarche is associated with a decrease in waist circumference, independent of height. Our results are consistent with Prentice and Viner's (2013) meta-analysis.

We found that in both urban and rural black South African women, an increase in leg-length relative to stature is associated with a decrease in waist circumference, independent of the timing of puberty. If we consider that leg-length is

a marker of pre-pubertal living conditions (Bogin & Varela-Silva, 2010; Frisancho, 2007), these results suggest that impaired growth in the pre-pubertal period is associated with the risks of accumulation of fat mass centrally. Comparable results were found in Peru (Pomeroy et al., 2014), South Africa (but not in the BT20 cohort) and other LMICs (Hales & Barker, 2001; Hoffman et al., 2000; Mamabolo et al., 2005; Mukuddem-Petersen & Kruger, 2004; Symington et al., 2015; but not in Cameron et al., 2005; Timaeus, 2012).

It is worth noting that, in urban women, timing of puberty, adult relative leg-length and height all independently predicted waist circumference; while in rural women we observed that only relative leg-length consistently predicted waist circumference. In the urban BT20 female participants, faster pubertal development and earlier age at menarche were associated with increased risks of overweight and obesity in adulthood and the association is partially mediated by pre-pubertal body size (height and body mass index) (Stein et al., 2016). Previous studies have found that children who had higher adiposity levels or who experienced rapid weight gain were at greater risk for earlier age at menarche and for overweight and obesity in adulthood (Ong et al., 2009; Prentice & Viner, 2013; Salgin et al., 2005). In line with these findings, it has been recently shown that childhood overweight/obesity and the associated decrease in insulin sensitivity could induce an early onset of puberty and favour fat mass accumulation from puberty onwards (Wilson et al., 2015).

Accordingly, we suggest that, for the urban black South African women of this study, the early life exposure to under-nutrition may have altered linear growth while the fast transition to an obesogenic environment during the pre-pubertal period may have favoured an earlier onset of puberty and have shortened the growth period. Both conditions, under- and over-nutrition, may have increased the risks of fat mass accumulation. As for rural black South African women in this study, we suggest that the persistence of adverse nutritional and environmental conditions for linear growth during the pre-pubertal period may have been the strongest determinants of age at menarche and adult height (McIntyre & Kacerosky, 2011). As a consequence, relative leg-length may be the strongest predictor of adiposity level in adulthood, in conjunction with ongoing changes towards obesogenic lifestyle in rural areas (Kimani-Murage, 2013).

Limitations

This study has a few limitations related to the nature of our cross-sectional data. Firstly, we relied on a retrospective self-reporting measure to determine the age of menarche. The risk of recall bias may be greater in urban young adult women as they are two years older than their rural counterparts. However, this method is commonly used to obtain the age at menarche and it has been shown that adult women are reliable when they report their age at menarche (Castilho et al., 2014). Secondly, we could not adjust our analysis for birthweight or childhood adiposity. Those data were not collected in the Ntshembo cross-sectional survey, unlike the

BT20 Cohort study. However, results of this study are in line with the findings from analyses using the full BT20 Cohort study, which were adjusted for childhood adiposity (Stein et al., 2016). The lack of psychosocial data during the pre-pubertal period further constrained the analysis and interpretation of the data. Given the social atmosphere in South Africa in the 1990s, other factors associated with premature puberty and early age at menarche including family disruption, father's absence, childhood adversity and continuous stress would have been worth taking into consideration (Anderson, 2015; Barbarin et al., 2001). Nevertheless, we retrieved the 1990s socio-demographic, socio-economic, health and nutrition information from previous publications describing the rural Agincourt HDSS site population and on psychosocial aspects of the BT20 Cohort.

Conclusion

This study shows that rural and urban young adult black South African women, born during the early years of the democratic transition in South Africa, differ in their age at menarche and in the relationship between age at menarche and adult stature and body proportions. Furthermore, an earlier age at menarche as well as a shorter stature both independently predicted more fat mass centrally. In a fast transitioning South Africa, where inequalities and poverty are still major issues, and where the double burden of malnutrition also fuels the co-existence of the epidemics of non-communicable and communicable diseases, it is important that forthcoming studies accurately describe and monitor growth and reproductive cycles in growing girls. In particular, future studies need to understand and disentangle the possible associations between the onset of puberty and the potential social, biological and psychological factors in the rural and urban South African context. Such information may help curb the escalation of the obesity and the associated chronic disease epidemics.

Disclosure statement

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References

Ameade EP, Garti HA. 2016. Age at menarche and factors that influence it: a study among female University students in Tamale, Northern Ghana. PLoS One 11:e0155310.

Anderson KG. 2015. Father absence, childhood stress, and reproductive maturation in South Africa. Hum Nat 26:401–425.

Armstrong ME, Lambert MI, Lambert EV. 2011. Secular trends in the prevalence of stunting, overweight and obesity among South African children (1994–2004). Eur J Clin Nutr 65:835–840.

Barbarin O, Richter L, deWet T. 2001. Exposure to violence, coping resources, and psychological adjustment of South African children. Am J Orthopsychiatry 71:16–25.

Beall J, Crankshaw O, Parnell S. 2002. Social differentiation and urban governance in greater Soweto: a case study of post-apartheid reconstruction.

Belachew T, Hadley C, Lindstrom D, Getachew Y, Duchateau L, Kolsteren P. 2011. Food insecurity and age at menarche among adolescent young adult women in Jimma Zone Southwest Ethiopia: a longitudinal study. Reprod Biol Endocrinol 9:125.

Bogin B, Varela-Silva MI. 2008. Fatness biases the use of estimated leg length as an epidemiological marker for adults in the NHANES III sample. Int J Epidemiol 37:201–209.

Bogin B, Varela-Silva MI. 2010. Leg length, body proportion, and health: a review with a note on beauty. Int J Environ Res Public Health 7:1047–1075.

Cameron N. 1984. The measurement of human growth. London: Croom Helm.

Cameron N, Kgamphe J, Levin Z. 1991. Age at menarche and an analysis of secular trends in menarcheal age of South African urban and rural black females. Am J Hum Biol 3:251–255.

Cameron N, Wright C. 1990. The start of breast development and age at menarche in South African black females. S Afr Med J 78:536–539.

Cameron N, Wright M, Griffiths P, Norris S, Pettifor J. 2005. Stunting at 2 years in relation to body composition at 9 years in African urban children. Obes Res 13:131–136.

Castilho S, Nucci L, Assuino S, Hansen L. 2014. The importance of memory bias in obtaining age of menarche by recall method in Brazilian adolescents. Arq Bras Endocrinol Metabol 58:394–397.

Clark SJ, Gomez-Olive FX, Houle B, Thorogood M, Klipstein-Grobusch K, Angotti N, Kabudula C, et al. 2015. Cardiometabolic disease risk and HIV status in rural South Africa: establishing a baseline. BMC Public Health 15:135.

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

Cole T. 2000. Secular trends in growth. Proc Nutr Soc 59:317–324.

Collinson MA, Tollman SM, Kahn K. 2007. Migration, settlement change and health in post-apartheid South Africa: Triangulating health and demographic surveillance with national census data. Scand J Public Health Suppl 35(69 Suppl):77–84.

Day T, Rowe L. 2002. Developmental thresholds and the evolution of reaction norms for age and size at life-history transitions. Am Nat 159:338–350.

Department of Health, SA MRC. 2002. South Africa Demographic and Health Survey 1998. Pretoria, South Africa: Department of Health/South Africa: Department of Health, Macro International.

Department of Health, SA MRC. 2007. South Africa Demographic and Health Survey 2003. Department of health.

Dubois L, Ohm Kyvik K, Girard M, Tatone-Tokuda F, Perusse D, Hjelmborg J, Skytthe A, et al. 2012. Genetic and environmental contributions to weight, height, and BMI from birth to 19 years of age: an international study of over 12,000 twin pairs. PLoS One 7:e30153.

Eastell R. 2005. Role of oestrogen in the regulation of bone turnover at the menarche. J Endocrinol 185:223–234.

Frisancho AR. 2007. Relative leg length as a biological marker to trace the developmental history of individuals and populations: growth delay and increased body fat. Am J Hum Biol 19:703–710.

Gomez-Olive FX, Angotti N, Houle B, Klipstein-Grobusch K, Kabudula C, Menken J, Williams J, et al. 2013. Prevalence of HIV among those 15 and older in rural South Africa. AIDS Care 25:1122–1128.

Hales C, Barker D. 2001. The thrifty phenotype hypothesis. Br Med Bull 60:5–20.

Hoffman D, Sawaya A, Verreschi I, Tucker K, Roberts S. 2000. Why are nutritionally stunted children at increased risk of obesity? Studies of metabolic rate and fat oxidation in shantytown children from Sao Paulo, Brazil. Am J Clin Nutr 72:702–707.

Houle B, Clark SJ, Gomez-Olive FX, Kahn K, Tollman SM. 2014. The unfolding counter-transition in rural South Africa: mortality and cause of death, 1994–2009. PLoS One 9:e100420.

Houle B, Pantazis A, Kabudula C, Tollman S, Clark SJ. 2016. Social patterns and differentials in the fertility transition in the context of HIV/AIDS: evidence from population surveillance, rural South Africa, 1993–2013. Popul Health Metr 14:10.

Inman RP, Rubinfeld DL. 2013. Understanding the democratic transition in South Africa. Am Law Econ Rev 15:1–38.

Janghorbani M, Mansourian M, Hosseini E. 2014. Systematic review and meta-analysis of age at menarche and risk of type 2 diabetes. Acta Diabetol 51:519–528.

Jelenkovic A, Sund R, Hur YM, Yokoyama Y, Hjelmborg JV, Moller S, Honda C. 2016. Genetic and environmental influences on height from infancy to early adulthood: an individual-based pooled analysis of 45 twin cohorts. Sci Rep 6:28496.

Jones LL, Griffiths PL, Norris SA, Pettifor JM, Cameron N. 2009a. Age at menarche and the evidence for a positive secular trend in urban South Africa. Am J Hum Biol 21:130–132.

Jones LL, Griffiths PL, Norris SA, Pettifor JM, Cameron N. 2009b. Is puberty starting earlier in urban South Africa? Am J Hum Biol 21:395–397.

Kagura J, Adair LS, Pisa PT, Griffiths PL, Pettifor JM, Norris SA. 2016. Association of socioeconomic status change between infancy and adolescence, and blood pressure, in South African young adults: Birth to Twenty Cohort. BMJ Open 6:e008805.

Kahn K, Collinson MA, Gomez-Olive FX, Mokoena O, Twine R, Mee P, Afolabi SA, et al. 2012. Profile: Agincourt health and socio-demographic surveillance system. Int J Epidemiol 41:988–1001.

Karapanou O, Papadimitriou A. 2010. Determinants of menarche. Reprod Biol Endocrinol 8:115.

Kimani-Murage E. 2013. Exploring the paradox: double burden of malnutrition in rural South Africa. Glob Health Action 6:19249.

Kimani-Murage EW, Kahn K, Pettifor JM, Tollman SM, Klipstein-Grobusch K, Norris SA. 2011. Predictors of adolescent weight status and central obesity in rural South Africa. Public Health Nutr 14:1114–1122.

Labadarios D, Steyn N, Maunder E, MacIntryre U, Gericke G, Swart R, Huskisson J, et al. 2005. The National Food Consumption Survey (NFCS): South Africa, 1999. Public Health Nutr 8:533–543.

Leenstra T, Petersen LT, Kariuki SK, Oloo AJ, Kager PA, ter Kuile FO. 2005. Prevalence and severity of malnutrition and age at menarche; cross-sectional studies in adolescent schoolgirls in western Kenya. Eur J Clin Nutr 59:41–48.

Leibbrandt M, Woolard I, Finn A, Argent J. 2010. Trends in South African income distribution and poverty since the fall of apartheid. Paris: OECD. No. 101.

Lohman T, Roche A, Martorell R. 1988. Anthropometric standardization reference manual. Champaign, IL: Human Kinetics Books.

Lundeen EA, Norris SA, Adair LS, Richter LM, Stein AD. 2016b. Sex differences in obesity incidence: 20-year prospective cohort in South Africa. Paediatr Obes 11:75–80.

Lundeen EA, Norris SA, Martorell R, Suchdev PS, Mehta NK, Richter LM, Stein AD. 2016a. Early Life Growth Predicts Pubertal Development in South African Adolescents. J Nutr 146:622–629.

Maddah M. 2009. Risk factors for overweight in urban and rural school young adult women in Iran: skipping breakfast and early menarche. Int J Cardiol 136:235–238.

Malina R. 2004. Secular trends in growth, maturation and physical performance: a review. Anthropol Rev 67:3–31.

Mamabolo R, Alberts M, Steyn N, Delemarre-van de Waal H, Levitt N. 2005. Prevalence and determinants of stunting and overweight in 3-year-old black South African children residing in the Central Region of Limpopo Province, South Africa. Public Health Nutr 8:501–508.

Maredza M, Bertram MY, Gomez-Olive XF, Tollman SM. 2016. Burden of stroke attributable to selected lifestyle risk factors in rural South Africa. BMC Public Health 16:143.

McDonald J, Eng S, Dina O, Schooling C, Terry M. 2016. Infection and pubertal timing: a systematic review. J Dev Orig Health Dis 7:636–651.

McIntyre MH, Kacerosky PM. 2011. Age and size at maturity in women: a norm of reaction? Am J Hum Biol 23:305–312.

McIntyre MH. 2011. Adult stature, body proportions and age at menarche in the United States National Health and Nutrition Survey (NHANES) III. Ann Hum Biol 38:716–720.

Mears RR. 1997. Improving economic development in greater Soweto: the role of local government. Africa Insight 27:178–187.

Mukuddem-Petersen J, Kruger HS. 2004. Association between stunting and overweight among 10-15-y-old children in the North West Province of South Africa: the THUSA BANA study. Int J Obes Relat Metab Disord 28:842–851.

NCD Risk Factor Collaboration. 2016. A century of trends in adult human height. Elife 5:e13410.

Nnyepi MS, Gwisai N, Lekgoa M, Seru T. 2015. Evidence of nutrition transition in Southern Africa. Proc Nutr Soc 74:478–486.

Norris S, Wrottesley S, Said-Mohamed R, Micklesfield L. 2014. Africa in transition: growth trends in children and implications for nutrition. Ann Nutr Metab 64:8–13.

Ong KK, Emmett P, Northstone K, Golding J, Rogers I, Ness AR, Wells JC, Dunger DB. 2009. Infancy weight gain predicts childhood body fat and age at menarche in girls. J Clin Endocrinol Metab 94:1527–1532.

Onland-Moret NC, Peeters PH, van Gils CH, Clavel-Chapelon F, Key T, Tjonneland A, Trichopoulou A, et al. 2005. Age at menarche in relation to adult height: the EPIC study. Am J Epidemiol 162:623–632.

Osuch JR, Karmaus W, Hoekman P, Mudd L, Zhang J, Haan P, Mikucki D. 2010. Association of age at menarche with adult leg length and trunk height: speculations in relation to breast cancer risk. Ann Hum Biol 37:76–85.

Pasquet P, Biyong AM, Rikong-Adie H, Befidi-Mengue R, Garba MT, Froment A. 1999. Age at menarche and urbanization in Cameroon: current status and secular trends. Ann Hum Biol 26:89–97.

Pomeroy E, Stock J, Stanojevic S, Miranda J, Cole T, Wells J. 2014. Stunting, adiposity, and the individual-level "dual burden" among urban lowland and rural highland Peruvian children. Am J Hum Biol 26:481–490.

Pradeilles R, Emily R, Norris SA, Griffiths PL. 2014. Urban South African adolescents' perceptions of their neighborhood socio-economic environments: the birth to twenty plus cohort study. Child Youth Environ 24:173–200.

Prentice P, Viner RM. 2013. Pubertal timing and adult obesity and cardio-metabolic risk in women and men: a systematic review and meta-analysis. Int J Obes (Lond) 37:1036–1043.

Ray S, Mishra SK, Roy AG, Das BM. 2010. Menstrual characteristics: a study of the adolescents of rural and urban West Bengal, India. Ann Hum Biol 37:668–681.

Richter L, Norris S, Pettifor J, Yach D, Cameron N. 2007. Cohort Profile: Mandela's children: the 1990 Birth to Twenty study in South Africa. Int J Epidemiol 36:504–511.

Said-Mohamed R, Micklesfield LK, Pettifor JM, Norris SA. 2015. Has the prevalence of stunting in South African children changed in 40 years? A systematic review. BMC Public Health 15:534.

Salgin B, Norris SA, Prentice P, Pettifor JM, Richter LM, Ong KK, Dunger DB. 2005. Even transient rapid infancy weight gain is associated with higher BMI in young adults and earlier menarche. Int J Obes (Lond) 39:939–944.

Saloojee H, De Maayer T, Garenne ML, Kahn K. 2007. What's new? Investigating risk factors for severe childhood malnutrition in a high HIV prevalence South African setting. Scand J Public Health 35:96–106.

Sartorius B, Kahn K, Vounatsou P, Collinson M, Tollman S. 2010. Young and vulnerable: spatial-temporal trends and risk factors for infant mortality in rural South Africa (Agincourt), 1992–2007. BMC Public Health 10:645.

Schooling CM, Jiang CQ, Lam TH, Zhang WS, Adab P, Cheng KK, Leung GM. 2010. Leg length and age of puberty among men and women from a developing population: the Guangzhou Biobank Cohort study. Am J Hum Biol 22:683–687.

Shisana O, Labadarios D, Rehle T, Simbayi L, Zuma K, Dhansay A, Reddy P. 2014. South African National Health and Nutrition Examination Survey (SANHANES-1): 2014 Edition. Cape Town: HSRC Press.

Sohn K. 2014. Age and size at maturity in Indonesian women: a norm of reaction? Am J Hum Biol 26:713–715.

Stats SA. 2012. Statistics South Africa (2012) Census 2011. Census in brief. [Online]. Statistics South Africa: Pretoria. Available online at: http://www.statssa.gov.za/census/census_2011/census_products/Census_2011_Census_in_brief.pdf (accessed November 5, 2016).

Stats SA. 2016a. Mid-year population estimates 2016. Available online at: http://www.statssa.gov.za/publications/P0302/P03022016.pdf (accessed November 5, 2016).

Stats SA. 2016b. Regional economic growth. Available online at: http://www.statssa.gov.za/economic_growth/16%20Regional%20estimates.pdf (accessed Septembre 19, 2017).

Stein AD, Lundeen EA, Martorell R, Suchdev PS, Mehta NK, Richter LM, Norris SA. 2016. Pubertal development and prepubertal height and weight jointly predict young adult height and body mass index in a prospective study in South Africa. J Nutr 146:1394–1401.

Steyn NP, Nel JH, Parker W, Ayah R, Mbithe D. 2012. Urbanisation and the nutrition transition: a comparison of diet and weight status of South African and Kenyan women. Scand J Public Health 40:229–238.

Symington EA, Gericke GJ, Nel JH, Labadarios D. 2015. The relationship between stunting and overweight among children from South Africa: Secondary analysis of the National Food Consumption Survey–Fortification Baseline I. S Afr Med J 106:65–69.

Tibazarwa K, Ntyintyane L, Sliwa K, Gerntholtz T, Carrington M, Wilkinson D, Stewart S. 2009. A time bomb of cardiovascular risk factors in South Africa: results from the Heart of Soweto Study "Heart Awareness Days". Int J Cardiol 132:233–239.

Timaeus IM. 2012. Stunting and obesity in childhood: a reassessment using longitudinal data from South Africa. Int J Epidemiol 41:764–772.

Turok I. 2012. Urbanisation and development in South Africa: economic imperatives, spatial distortions and strategic responses. London: International Institute for Environment and Development. N°8.

Vorster HH, Kruger A, Margetts BM. 2011. The nutrition transition in Africa: can it be steered into a more positive direction? Nutrients 3:429–441.

Wilson DA, Derraik JG, Rowe DL, Hofman PL, Cutfield WS. 2015. Earlier menarche is associated with lower insulin sensitivity and increased adiposity in young adult women. PLoS One 10:e0128427.

Yermachenko A, Dvornyk V. 2014. Nongenetic determinants of age at menarche: a systematic review. Biomed Res Int 2014:371583.