Under- and overnutrition and evidence of metabolic disease risk in rural black South African children and adolescents

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Abstract

Objectives: The objective was to determine the prevalence of under- and overnutrition, as well as evidence of metabolic disease risk in rural black South African children and adolescents.

Design: A cross-sectional study was conducted.

Setting: The setting was the Agincourt Health and Socio-demographic Surveillance System site, Mpumalanga province.

Subjects: Six hundred children were randomly selected, of whom 588 were included in the analytical sample (mean age of 11.5 years, range of 7-15 years).

Outcome measures: Outcome measures were anthropometric and blood pressure assessments, Tanner pubertal staging, as well as the determination of fasting serum lipid and glucose concentrations.

Results: Using age and sex-specific World Health Organization 2007 growth references, the prevalence of stunting was determined to be 6.2% in the boys, and 2.7% in the girls, while 4.1% of the boys and 4.4% of the girls were underweight. Combined overweight and obesity prevalence was higher in the girls (13.5%) than in the boys (2.7%). Girls had significantly a higher body mass index and hip circumference than the boys in the early, mid and late pubertal stages. Pre-hypertension prevalence, using either systolic or diastolic blood pressure for sex, age and height, was 15% and 10% in the girls and boys, respectively. Furthermore, impaired fasting glucose (FG) (FG $\geq$ 5.6 mmol/l) was detected in 5% of the children. High-density lipoprotein cholesterol concentrations less than 1 mmol/l were observed in 0.7% of the boys and in 12% of the girls, which is indicative of cardiometabolic risk.

Conclusion: Stunting levels were higher in the boys than in the girls in mid to late childhood in a rural setting in South Africa, while the girls had a higher prevalence of overweight and obesity than the boys. Pre-hypertension prevalence in the boys and girls was high. Other metabolic risk factors, i.e. impaired FG and lipids, were also seen in this population and were associated with adiposity. The study highlights the critical need for targeted health promotion interventions to optimise child health as part of a noncommunicable disease preventative strategy.

Introduction

It is estimated that by 2020, noncommunicable diseases will account for three quarters of all deaths in developing countries, and will be associated with increasing prevalence in the young in low- and middle-income countries.[1] Obesity is likely to increase in South Africa as a result of an ongoing lifestyle transition from a traditional rural to more urban "Westernised" lifestyle, characterised by a less healthy diet, reduced physical activity and increased sedentary behaviour.[2,3]

Fifteen years ago, 18.5% and 3% of rural children aged 7-9 years in South Africa were stunted and obese.[4] The recent National Health and Nutrition Examination Survey (SANHANES-1) showed that the

prevalence of stunting in the 7- to 9-year-old age group was 10% and 8.7% for boys and girls, respectively. Also, the prevalence of overweight and obesity was significantly higher in girls than in boys aged 15-17 years (19.3% and 8%, compared to 7.3% and 1.5%, for females and males, respectively).[5] A 2008 study, the 2nd Youth Risk Behaviour Survey, found that 11% of male and 29% of female adolescents in grades 8-11 (approximate age of between 13 and 19 years) were overweight.[6] Other recent studies have confirmed the coexistence of under- and overnutrition in both rural and urban South African children.[7-10]

Research on malnutrition and metabolic disease risk factors in children is vital[11] given the limited data in rural South Africa, where

lifestyle transitions are expected to be the most dramatic over the next decade.[3,7] The aim of this study was to determine the prevalence of under-and overnutrition, as well as evidence of early metabolic disease risk in rural South African children and adolescents. The Agincourt Health and Socio-demographic Surveillance System site (HDSS) provided an opportunity for study participants to be randomly selected.

Method

Setting and study population

The study was nested in the Agincourt HDSS in rural Mpumalanga province. Detailed information on the study area and Agincourt HDSS has been published previously.[7,12,13] The study area, bordering the Kruger National Park in north-east South Africa, is divided into plots that are generally too small to support reasonable subsistence farming, and the level of income is low by South African standards.[7,12,13] In 2007, 3 489 black South African children and adolescents aged 1-20 years were randomly chosen from the Agincourt HDSS villages in a growth survey.[13] In 2009, we randomly selected 600 participants, in the 7- to 8-year; 11- to 12-year and 14- to 15-year age groups from this study (200 participants in each group). Ethical approval was granted by the University of the Witwatersrand Human Subjects Research Committee Clearance No. M090212, and from the Mpumalanga Provincial Department of Health. Permission from community leaders and school principals was also obtained. Signed informed consent was provided by the parents and assent given by the children.

Anthropometric measurements

Anthropometric measurements were performed according to standard procedures.[14] Heights were measured using a stadiometer calibrated to the nearest 0.1 cm. The participants were weighed to the nearest 0.1 kg using a digital bathroom scale. The equipment was checked and calibrated daily before use. The girls and boys were measured in separate classrooms. Waist circumference (WC) was measured using an inelastic tape measure midway between the tenth rib and the iliac crest. In 2007 and 2009, hip circumference (HC) was measured at the level of maximum width of the buttocks, with the participants standing.[14] Skin fold (triceps, biceps, subscapular and suprailiac) measurements were made to the nearest 0.2 mm using a reliable calliper. The triceps and biceps skin folds were consistently measured in the non-dominant arm. Three measurements of triceps, biceps, subscapular and suprailiac skin fold thickness were taken, and the average of the four sites' measurements was used in the analysis. Participants with complete four skin fold measurements were included in the study (86.7%). Anthropometric measurements were performed by two trained fieldworkers. Both intra- and inter-observer variability were measured before the study commenced and during its course. The anthropometric measurement variation remained below 2%. A male and a female were used in order to provide both the boys and girls with gender-specific assistance during measurement.

Pubertal assessment

Participants self-reported their pubertal development using a validated questionnaire for black South Africans based on the Tanner staging criteria.[15] Pubic hair was assessed in both the boys and girls, as well as breast development in the girls and genitalia in the boys, for this study. The subjects were classified as prepubertal if they were at Tanner stage 1, early pubertal if they were at Tanner stage 2 and mid pubertal if they were at Tanner stage 3. Owing to the small number of participants, Tanner stages 4 and 5 were combined to represent late pubertal.[15]

Blood pressure measurements

Three measurements of systolic blood pressure (SBP) and diastolic blood pressure (DBP) were taken from participants after 5-10 minutes of quiet rest using an Omron® M6 blood pressure monitor (Omron, Kyoto, Japan). The first reading was discarded and the subsequent two readings were averaged for analysis. The blood pressure data were classified according to age-, sex- and height-specific cut-off points, based on the National High Blood Pressure Education Program Working Group.[16]

Biochemical measurements

Two trained nurses collected a 12 hour fasting venous blood sample from the participants in the morning, i.e. between 08h00 and 10h00, to determine glucose, cholesterol, high-density lipoprotein (HDL) cholesterol, low-density lipoprotein (LDL) cholesterol and triglyceride (TG) concentrations. The blood samples for glucose analysis were collected in grey top tubes containing sodium fluoride, while lipids were collected in clot activator tubes. Both were centrifuged. The plasma and the serum were separated and stored in a freezer at −70°C in the Agincourt laboratory. The samples were later transported to Johannesburg, packed in dry ice, and stored at −70°C until analysed. Both glucose and lipid profiles were measured using the chemiluminescence RX® daytona analyser (Crumlin Co, Antrim, Northern Ireland).[17]

Data analysis

Age and sex appropriate z-scores for weight and height were generated using the World Health Organization (WHO) 2007 growth references.[18] Body mass index (BMI) and BMI z-scores were calculated for each participant. Levels of overweight and obesity were determined using Cole's international BMI cut-off points.[19]

The risk of adiposity was assessed using waist-to-hip ratio (WHR) of > 0.85 for females, > 0.90 for males,[20] waist-to-height ratio (WHtR) of > 0.5 for both sexes,[21] and WC of ≥ 80 cm for the females and ≥ 94 cm for the males. As these are adult cut-offs points, a conservative approach was chosen to apply the cut-off points for WHR and WC only to those participants in Tanner stage 3 or greater, as they would be closer to attaining their final adult height. However, this was not applied to WHtR. In addition, impaired fasting glucose of ≥ 5.6 mmol/l was calculated according to International Diabetes Federation standards.[22] The following cut-offs were used for abnormal lipids: HDL cholesterol of > 1.03 mmol/l, LDL cholesterol

Table I: The characteristics of the study participants according to sex and age

Variables	7-8 years (n = 197)			11-12 years (n = 202)			14-15 years (n = 189)		
	Boys (n = 98)	Girls (n = 99)	p-value	Boys (n = 102)	Girls (n = 100)	p-value	Boys (n = 92)	Girls (n = 97)	p-value
Mean age (years) (SD), n = 588	7.5 (0.5)	7.6 (0.5)	0.178	11.5 (0.5)	11.5 (0.5)	0.780	14.5 (0.5)	14.5 (0.5)	0.430
Mean weight (kg) (SD), n = 588	25 (4)	26 (6)	0.240	43 (11.3)	48 (13.1)	0.000*	51 (11.1)	55.3 (10)	0.003*
Mean height (cm) (SD), n = 588	126.3 (6.1)	127.5 (6)	0.16	145 (7)	149 (8)	0.000*	163.1 (8.6)	160 (5.5)	0.002*
Mean BMI (kg/m^2) (SD), n = 588	15.6 (1.7)	16 (2.5)	0.613	17 (2)	18 (3.4)	0.004*	19 (2.4)	22 (4.1)	0.000*
Mean WC (cm) (SD), n = 588	55.4 (4.3)	52.7 (5.2)	0.000*	60.3 (5.2)	60.6 (7.2)	0.780	67 (6.3)	68 (9.4)	0.351
Mean HC (cm) (SD), n = 588	63.2 (0.5)	65 (0.7)	0.142	72 (0.7)	80 (1)	0.000*	80 (1.3)	90 (1.2)	0.000*
Mean SBP (mmHG) (SD), n = 523	99 (12)	95.5 (12.4)	0.074	98.3 (12.4)	106 (14.5)	0.000*	111 (12.3)	112.3 (10.7)	0.423
Mean DBP (mmHG) (SD), n = 523	58.5 (12.1)	58.3 (11)	0.907	59 (8)	61.2 (12)	0.076	64 (8)	65 (7.4)	0.433
Sum of skin folds (mm) (IQR, n = 509	5.3 (4.6-5.9)	6 (5.1-7)	0.000*	5.5 (4.8-6.2.)	5.3 (4.4-6)	0.130	5.8 (5.1-6.8)	9 (7.4-9.8)	0.000*
Mean HDL cholesterol (mmol/l), (SD), n = 371	1.1 (0.4)	1.3 (0.3)	0.032*	1.2 (0.3)	1.2 (0.3)	0.700	1.2 (0.3)	1.2 (0.3)	0.770
Mean LDL cholesterol (mmol/l), (SD), n = 367	2 (0.6)	2 (0.6)	0.560	2 (0.7)	2 (0.6)	0.174	2 (0.5)	2 (0.6)	0.335
Mean TGs (mmol/l) (SD), n = 388	0.8 (0.3)	0.8 (0.3)	0.830	0.8 (0.3)	1 (0.5)	0.185	0.8 (0.3)	0.8 (0.3)	0.220
Mean TC (mmol/l) (SD), n = 388	4 (0.7)	4.1 (0.8)	0.242	4.1 (0.8)	4.2 (0.8)	0.111	3.8 (0.6)	4 (0.7)	0.145
Mean glucose (mmol/l) (SD), n = 357	4.6 (0.8)	4.7 (0.8)	0.520	5 (0.7)	4.6 (1.1)	0.200	5 (0.6)	4.8 (0.5)	0.070

*statistically significant

BMI: body mass index, DBP: diastolic blood pressure, HC: hip circumference, HLD: high-density lipoprotein, IQR: interquartile range, LDL: low-density lipoprotein, SBP: systolic blood pressure, SD: standard deviation, TGs: triglycerides, TC: total cholesterol, WC: waist circumference

of > 2.59 mmol/l, TGs of ≥ 1.7 mmol/l and total cholesterol (TC) of > 5.17 mmol/l.[5,23,24] Pre-hypertension was defined as the average of the last two readings of SBP or DBP, being ≥ 90th but < 95th percentile for age, sex and height.[16]

Normally distributed continuous variables were expressed as means with standard deviation. Student's t-test was used to test for differences between the means by sex with a significance level of p-value < 0.05. The median and interquartile range is given for the sum of the skinfold thicknesses owing to skewness. The chi-square test was used to test for significant associations between the categorical variables, while Fisher's exact test was used when the cell frequencies were < 5. Linear regression was employed to test associations. The statistical analyses were performed using Stata® version 11.

Results

Characteristics of participants

Twelve of the original 600 children were not in residence at the time of the study, thus 588 (98%) were seen. Fasting venous blood samples were only obtained from 387 (66%) participants because assent was not given for venipuncture (25.5%), or owing to an inability to obtain a blood sample (8.5%). Table I presents the general characteristics of the study sample by sex and age. The 11- to 12-year-old females were slightly heavier and taller than the males, while the 14- to 15-year-old girls were shorter and heavier than the boys. The girls' BMI was significantly greater at ages 11 and 12 years than that of the boys [girls: 18 ± 3.4, 95% confidence interval (CI): 17.33-18.69; boys: 17 ± 2, 95% CI: 16.46-17.25; p-value 0.004] and at ages 14-15 years (girls: 22 ± 4.1, 95% CI: 20.82-22.47; boys: 19 ± 2.4, 95% CI: 18.39-19.38; p-value < 0.001). The younger girls, aged 7-8 years, had a smaller WC (p-value < 0.001), while the girls aged 11-12 years and 14-15 years had a larger HC than the boys (p-value < 0.001). The sum of the skin fold measurements for the girls in the 7- to 8-year-old, and 14- to15-year-old, groups, was significantly higher than that for the boys.

The prevalence of under- and overnutrition

Table II displays the prevalence of malnutrition and the metabolic risk characteristics of study participants by sex. Significantly, more

Table II: Prevalence of malnutrition and metabolic risk factors according to sex

Variables	Boys (n = 292)	Girls (n = 296)	p-value, χ^2
Mean age in years (SD)	11.1 (3)	11.1 (3)	0.840
*HAZ < −2 SD: stunted, n (%)	18 (6.2)	8 (2.7)	0.041, 4.168
*WAZ < −2 SD: underweight, n (%)	12 (4.1)	13 (4.4)	0.865, 0.030
*WHZ < −2 SD: wasted, n (%)	3 (1)	1 (0.3)	0.310, 1.035
*BMI 25-29.9 kg/m²: overweight, n (%)	6 (2.1)	31 (10.5)	0.000, 17.700
*BMI ≥ 30 kg/m²: obese, n (%)	2 (0.7)	9 (3)	0.035, 4.443
*BMI ≥ 25 kg/m²: overweight and obese, n (%)	8 (2.7)	40 (13.5)	0.000, 22.800
WHtR > 0.5, n (%)	39 (13.4)	49 (16.6)	0. 277, 1.181
TC (borderline high): 5.17-6.18 mmol/l, n = 388, n (%)	3 (1.5)	16 (8.5)	0.002, 10.077
TGs > 1.7mmol/l, n = 388, n (%)	3 (1.6)	8 (4.01%)	0.110, 2.560
Pre-hypertensive SBP and DBP, n = 523, n (%)	26 (10)	40 (15)	0.051, 3.100
IFG (FG ≥ 5.6 mmol/l), n = 357, n (%)	9 (5)	9 (5.3%)	0.522, 0.034

*Derived from age-specific z-scores

χ^2: chi-square, BMI: body mass index, DBP: diastolic blood pressure, FG: fasting glucose, HAZ: height-for-age z-scores, IFG: impaired fasting glucose, SBP: systolic blood pressure, SD: standard deviation, TC: total cholesterol, TGs: triglycerides, WAZ: weight-for-age z-scores, WHtR: waist-to-height ratio, WHZ: weight-for-height z-scores

Table III: Factors associated with blood pressure adjusted for sex and pubertal stage (linear regression)

SBP (mmHg), n = 523	β	95% CI	p-value
BMI (kg/m²)	0.80	0.08-1.50	0.030*
Sum of skin folds (mm)	3.56	2.38-4.74	0.000*
WC (cm)	0.28	−0.18-0.58	0.066
HC (cm)	0.00	−0.01-0.03	0.515
DBP (mmHg), n = 523	β	95% CI	p-value
BMI (kg/m²)	0.12	−0.20-0.62	0.636
Sum of skin folds (mm)	-0.32	−1.22-0.60	0.490
WC (cm)	0.20	−0.11-0.31	0.372
HC (cm)	0.00	−0.00-0.02	0.366

*statistically significant

BMI: body mass index, CI: confidence interval, DBP: diastolic blood pressure, HC: hip circumference, SBP: systolic blood pressure, WC: waist circumference

boys (6.2%) than girls (2.7%) were stunted (p-value 0.04), and a similar sex prevalence of underweight was noted (4.1% of the boys and 4.4% of the girls).

In the three age groups, stunting was significantly greater in boys (4.2%) than in girls (0.5%) aged 14-15 years (p-value 0.031), while 4.5% vs. 3.5% (11- to 12-year-old) and 0.5% vs. 0% (7- to 8-year-old) boys and girls were stunted, respectively. The prevalence of underweight was higher in the 11- to 12-year-old girls (4%) than it was in the boys (2.5%), and higher in the boys than in the girls aged 14-15 years (2.6% vs. 1.6%). The prevalence of underweight in the 7- to 8-year-old age group was 1% for both the boys and girls, respectively. The prevalence of wasting was 1.3% in the boys compared to (0.3%) in the girls aged 7-8 years. There were no significant differences by sex in underweight in the three age groups and wasting in the 7- to 8-year-old age group. The prevalence of combined overweight and obesity was significantly higher in the girls than in the boys (13.5% and 2.7%, respectively, p-value < 0.001).

Risk factors for metabolic disease

Indicators of adiposity in the participants at Tanner stage 3 or greater highlighted that 2.2% of the girls and none of the boys had a WC above the adult risk cut-off point. WHR was higher in the girls (17.2%) than in the boys (2%, p-value < 0.001). Across all of the participants, 13.4% of the boys and 16.6% of the girls had a WHtR above the cut-off point (Table II).

Just over 5% of the boys and girls had impaired FG. Using TC concentrations, more girls (8.5%) than boys (1.5%) had levels above the normal range in the borderline high category (p-value 0.002) (Table II). 10.7% of the boys and 12% of the girls had concentrations of HDL cholesterol less than 1 mmol/l, which is indicative of cardiometabolic risk. Only 2.3% of the girls had borderline high LDL cholesterol concentrations, and 13.1% of the girls and 8.7%

of the boys had near optimal LDL cholesterol concentrations. There were no mean differences by sex for LDL and HDL cholesterol and triglycerides. Pre-hypertension, using either SBP or DBP, for sex, age and height was 15% and 10% in the girls and boys, respectively. The figures were similar across the age groups. After adjusting for sex and the pubertal stages of development, SBP was associated with indicators of obesity and adiposity [sum of the skin folds (p-value < 0.001), BMI (p-value 0.03) and WC (p-value 0.06] (Table III).

Characteristics of the study participants stratified by sex and Tanner stages of pubertal development

Table IV summarises the anthropometry characteristics, and lipid profiles and blood pressure by Tanner stages of pubertal development (n = 574, 2% declined). Significant sex differences were observed with respect to height in the children at the pre- and late pubertal stages, while girls had a smaller WC in the pre-pubertal group. Girls' BMI and HC values were significantly higher than that of the boys at the early (p-value 0.031 and p-value < 0.001), mid (p-value 0.002 and p-value 0.004), and late (p-value < 0.001) pubertal stages. The female participants had a higher sum of skin fold measurements during the pre-, mid and late pubertal stages (p-value < 0.001, p-value 0.002 and p-value 0.001, respectively) (Table IV). There was no difference in the lipid profile with advancing puberty. However, there were significant differences between the sexes in certain pubertal stages. In particular, girls had higher LDL cholesterol than the boys at the mid-pubertal stage (girls: 2 ± 0.6, 95% CI: 1.82-2.17; boys: 1.7 ± 0.5, 95% CI: 1.54-1.91, p-value 0.030), and the girls had a higher TC mean at the early pubertal stage than the boys (girls: 4.2 ± 0.7, 95% CI: 3.95-4.5; boys: 3.8 ± 0.7, 95% CI: 3.59-4.10, p-value 0.050) and at the mid-pubertal stage (girls: 4 ± 0.7, 95% CI: 3.83-4.23; boys: 3.7 ± 0.7, 95% CI: 3.52-3.94, p-value 0.045) (Table IV). Female participants had a higher BMI, BMI-for-age z-score, and HC (p-value < 0.001) than males as they progressed through

Table IV: Characteristics [means (standard deviation)] of the study participants stratified by sex and Tanner stages of development

Tanner stages	Pre-pubertal			Early pubertal			Mid-pubertal			Late pubertal		
	Boys (n = 147)	Girls (n = 116)	p-value	Boys (n = 46)	Girls (n = 51)	p-value	Boys (n = 54)	Girls (n = 70)	p-value	Boys (n = 38)	Girls (n = 52)	p-value
Mean age (years) (SD), n= 574	9 (2.3)	8.2 (1.5)	0.001*	12.2 (1.3)	12 (1)	0.071	13.53 (1.5)	13.3 (1.4)	0.344	14.4 (0.9)	14.4 (0.8)	0.850
Mean weight (kg) (SD), n = 574	28.6 (7.2)	26.6 (6)	0.012*	37.3 (8)	42 (10)	0.013*	46.1 (9.2)	48.2 (8)	0.170	54 (12)	60.1 (13)	0.022*
Mean height (cm) (SD), n = 574	133 (11.3)	130 (8.1)	0.023*	147 (8.4)	149.4 (8)	0.135	158.2 (10.3)	157 (7)	0.337	166 (8.2)	160 (6)	0.000*
Mean BMI (kg/m²) (SD), n = 574	16 (2)	16 (2.3)	0.172	17.1 (2.3)	18.4 (3.4)	0.031*	18.2 (2.1)	20 (3)	0.002*	20 (3)	23.5 (5)	0.000*
Mean WC (cm) (SD), n = 574	57.1 (5.5)	53 (5)	0.000*	61 (6)	61.3 (7.2)	0.783	65 (6)	64 (7.1)	0.476	68 (7)	71 (10)	0.158
Mean HC (cm) (SD), n = 574	65.8 (0.6)	65.3 (0.7)	0.526	73 (0.6)	80 (1)	0.000*	78 (1.2)	84 (1.2)	0.004*	81 (1.4)	93.4 (1.1)	0.000*
Mean HDL cholesterol (mmo/l), (SD), n = 371	1.2 (0.3)	1.2 (0.4)	0.250	1.3 (0.3)	1.2 (0.3)	0.888	1.2 (0.3)	1.2 (0.3)	0.600	1.2 (0.2)	1.2 (0.3)	0.638
Mean LDL cholesterol (mmo/l), (SD), n = 367	1.9 (0.6)	1.9 (0.6)	0.905	1.8 (0.6)	2 (0.7)	0.244	1.7 (0.5)	2 (0.6)	0.030*	1.8 (0.5)	1.8 (0.6)	0.763
Mean TC (mmo/l) (SD), n = 388	4 (0.7)	4.1 (0.8)	0.800	3.8 (0.7)	4.2 (0.7)	0.050*	3.7 (0.7)	4 (0.7)	0.045*	3.7 (0.5)	3.9 (0.7)	0.140
Mean TGs (mmo/l) (SD), n = 388	0.8 (0.3)	0.8 (0.3)	0.773	0.8 (0.2)	1 (0.6)	0.180	0.8 (0.3)	0.8 (0.3)	0.900	0.7 0.20	0.8 (0.3)	0.180
Mean glucose (mmo/l) (SD), n = 357	4.7 (0.7)	4.6 (1)	0.270	5 (0.5)	4.5 (1.3)	0.200	5 (0.8)	4.7 (0.6)	0.350	5 (0.8)	5 (0.5)	0.423
Mean SBP (mmHG) (SD), n = 523	96.6 (12.9)	99.3 (14)	0.141	101 (13.2)	125 (13.8)	0.240	106 (11)	111 (12.2)	0.021*	113.3 (14.6)	112.2 (10.3)	0.700
Mean DBP (mmHG) (SD), n = 523	59 (11)	59 (12)	1.000	60 (9.5)	61.2 (12)	0.500	62.3 (7.3)	62 (8.1)	0.850	64 (8.1)	67 (7)	0.057
Sum of skin folds (mm) (Median IQR), n = 503	5.3 (4.6-6)	5.9 (5-7)	0.000*	5.8 (5.3-6.3)	5.9 (4.4-6.8)	0.942	5 (4.6-6.8)	7 (5.3-9)	0.002*	5.6 (5.1-6.9)	9.3 (7.4-10)	0.000*

*statistically significant

BMI: body mass index, DBP: diastolic blood pressure, HC: hip circumference, HLD: high-density lipoprotein, IQR: interquartile range, LDL: low-density lipoprotein, SBP: systolic blood pressure, SD: standard deviation, TGs: triglycerides, TC: total cholesterol, WC: waist circumference

puberty, while boys had a higher WC than the girls (p-value < 0.001). A difference in blood pressure between the boys and the girls (p-value 0.021) was only found at mid-puberty.

Table V presents changes in the various anthropometric parameters with regard to FG, TGs and HDL cholesterol from 2007-2009. A change in HC and WC was significantly associated with FG (β 0.01, p-value 0.020 and β 0.01, p-value 0.002, respectively). A change in WC and WHtR was significantly associated with TGs (β 2.4, p-value 0.050 and β 0.02, p-value 0.050, respectively). Also, a change in WC and HC was significantly associated with HDL cholesterol (β −2.7, p-value 0.050 and β −4.1, p-value 0.053, respectively). However, a change in the BMI and BMI-for-age z-score was not significantly associated with FG, TGs and HDL cholesterol. Examining the changes in anthropometric measures over two years revealed that indicators of central adiposity were positively associated with glucose concentrations and TGs in the participants.

Discussion

To our knowledge, this is the first study that has examined both malnutrition and metabolic disease risk factors in South African children aged 7-8, 11-12 and 14-15 years. National South African and cross-sectional studies have reported the coexistence of under- and overnutrition in children and adolescents.[4-11] However, limited information exists on the prevalence of metabolic disease risk factors in rural children.[3,7]

In this study, the prevalence of undernutrition in children aged 7-8 years was lower than the national prevalence in rural children.[4,5] Our findings of a higher prevalence of stunting in 11- to 12- and 14- to 15-year-old boys than in girls is similar to an earlier study on adolescence.[25] However, this stunting prevalence was lower than that reported in the National Youth Risk Behaviour Survey in 2008.[26] This higher prevalence of stunting in boys may be owing to a combination of nutrition and other factors. There was no evidence

Table V: The correlation between fasting glucose, triglycerides and high-density lipoprotein cholesterol and a change in body mass index and BMI-for-age z-score, hip and waist circumference, and waist-to-height ratio from 2007-2009

Variable	β	95% CI	t	p-value
FG (mmol/l) (n = 312)				
Change in BMI (kg/m²)	0.13	−0.08 to 0.35	1.20	0.233
Change in BMI-for-age z-score	0.08	−0.05 to 0.20	1.20	0.233
Change in HC (cm)	0.01	0.00 to 0.01	2.37	0.020*
Change in WC (cm)	0.01	0.01 to 0.02	3.17	0.002*
Change in WHtR	0.01	−0.00 to 0.16	1.84	0.070
TGs (mmol/l) (n = 388)				
Change in BMI (kg/m²)	−0.12	−0.60 to 0.04	−0.50	0.644
Change in BMI-for-age z-score	−0.10	−0.40 to 0.23	−0.50	0.644
Change in WC (cm)	2.4	0.05 to 4.80	2.01	0.050*
Change in HC (cm)	3.1	−0.06 to 6.83	1.67	0.096
Change in WHtR	0.02	0.00 to 0.03	2.01	0.050*
HDL cholesterol (mmol/l) (n = 367)				
Change in BMI (kg/m²)	0.03	−0.06 to 0.61	0.10	0.920
Change in BMI-for-age z-score	0.02	−0.02 to 0.35	0.10	0.920
Change in WC (cm)	−2.7	−5.34 to −0.03	−2.01	0.050*
Change in HC (cm)	−4.1.	−8.20 to 0.56	−2.0	0.053*
Change in WHtR	−0.013	−0.03 to 0.01	−1.35	0.176

*statistically significant
BMI: body mass index, CI: confidence interval, FG: fasting glucose, HC: hip circumference, HDL: high-density lipoprotein, TGs: triglycerides, WC: waist circumference, WHtR: waist-to-height ratio

that there were significant household socio-economic differences between the sexes (unpublished data). Further investigation into dietary patterns and intake is warranted.[12,13,27] The difference in stunting prevalence between the boys and girls may, in part, be explained by the fact that there is some evidence that urban black, South African adolescent boys have a later onset of pubertal development and skeletal maturity (Birth to Twenty longitudinal data, unpublished) than their white peers. If this is the case, in this rural setting, a comparison of height with the WHO reference could result in a temporal overestimate of stunting as the rural boys may be in an earlier stage of maturity generally.

The prevalence of overnutrition in this study was also lower than that observed in the recent (SANHANES) study on 15- to 17-year-old adolescents.[5] However, our study, which is consistent with other studies, found that overweight and obesity were greater in the girls than in the boys.[7,9,10] The differences in overnutrition by sex in this study may be owing to differences in physical activity levels.[27] Our data have demonstrated that moderate to vigorous physical activity was significantly higher in older male subjects than in female subjects, and that informal activity was lower in the boys than the girls, while sedentary time was higher in the older girls (aged 14-15 years) than in the younger girls (aged 11-12 years).[27] Also, there has

been increasing temporary rural-urban migration[28] and availability of fast food vendors in this area.[29] The increasing prevalence of childhood obesity may have potential long-term medical risks, such as type 1 and type 2 diabetes mellitus, cardiovascular disease, orthopaedic complications[30] and new-onset asthma.[31]

Global trends indicate that pre-hypertension is on the rise in children and adolescents.[32,33] Given that pre-hypertension is strongly predictive of future hypertension and the development of other noncommunicable diseases,[32,34] the prevalence of 12.6% in this study on children is of concern (Table II). Furthermore, it was surprising to detect the levels of impaired FG and abnormal lipid profiles in this rural population at these younger ages. The factors that were associated with SBP in this study, e.g. glucose concentrations and lipid profile, are indicators of adiposity: both subcutaneous (sum of the skin folds) and abdominal (WC). Therefore, changes in adiposity during childhood, and with pubertal development, as seen in the girls, confer metabolic disease risk.[35]

A study on children in the USA found that the percentage of fat, as measured by skin folds, related to metabolic risk factors, such as lipids, blood pressure and C-reactive protein.[36] In our study, we observed that the percentage of fat was associated with impaired fasting glucose, low HDL cholesterol and high LDL cholesterol, as well as TC.

This study could have a limitation in that 30% of the sample were of Mozambican origin, thus resembling major differences (maternal socio-economic status and other distal measures) from the core sample that mainly comprised South Africans. The strengths of our study were the longitudinal assessment of body composition and its relationship to metabolic disease risk in a rural setting in South Africa. In addition, the measurements were performed by experienced fieldworkers who followed standardisation procedures used in the Birth to Twenty longitudinal cohort. However, the results of this study cannot be overly extrapolated to other rural settings or population groups. Nevertheless, as this study community represents relatively poor rural villages with little subsistence farming, it is reasonable to assume that other rural villages that are further along the nutrition transition may have even higher metabolic risk factors than those observed in this study. Future research is warranted to investigate early signs of metabolic risk factors in South African children longitudinally, and to identify which environmental factors contribute to metabolic disease risk.

Conclusion

This study highlights a rural area in which late childhood undernutrition was present, but less than overnutrition, particularly in girls. The emergence of early pre-hypertension risk was concerning, as well as the higher-than-expected levels of impaired fasting glucose and abnormal lipid profiles, particularly in the girls. The implication is that rural South African communities are mirroring more urban environments in terms of metabolic risk profiles, which are indicative of a rapid nutritional and economic transition. Therefore, it is critical

that health-promotion initiatives recognise that early childhood is a window of opportunity from which to ensure that children remain on a healthy journey to adulthood. Thus, risk-reduction policies need to be implemented in order to stem the advance of obesity and metabolic disease risk, as recommended by the WHO. This can be achieved through revitalised school health programmes, such as the early introduction of nutrition education, ensuring that children have access to healthy foods at schools and within the school vicinity, as well regulating "junk food" advertisements in the media that target children. In addition, children and adolescents should be encouraged to spend more time in physical activity, both at school and at home.

Acknowledgement

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