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The prevalence and factors associated with stunting among infants aged 6 months in a peri-urban South African community

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Abstract

Objective: To determine the prevalence and factors associated with stunting in 6-month-old South African infants.

Design: This cross-sectional study was part of the baseline of a randomized controlled trial. Weight-for-length, length-for-age and weight-for-age *Z*-scores were based on the WHO classification. Blood samples were analysed for Hb, plasma ferritin and soluble transferrin receptor (sTfR). Socio-economic, breast-feeding and complementary feeding practices were assessed by questionnaire.

Setting/Subjects: Infants aged 6 months (*n* 750) from a peri-urban area of Matlosana Municipality, North West Province of South Africa.

Results: Stunting, underweight, wasting and overweight affected 28·5, 11·1, 1·7 and 10·1 % of infants, respectively. Exclusive breast-feeding to 6 months of age was reported in 5·9 % of the infants. Multivariable binary logistic regression showed that birth weight (OR = 0·12; 95 % CI 0·07, 0·21, $P < 0·001$) and maternal height (OR = 0·94; 95 % CI 0·91, 0·98, $P = 0·001$) were inversely associated with stunting; while male sex (OR = 1·73; 95 % CI 1·10, 2·70, $P = 0·014$) was associated with higher odds for stunting. Stunting was also associated with higher plasma sTfR (>8·3 mg/l) concentrations.

Conclusions: The association between stunting and lower birth weight, shorter maternal height and male sex reflects possibly the intergenerational origins of stunting. Therefore, interventions that focus on improving preconceptual and maternal nutritional status, combined with strategies to promote appropriate infant feeding practices, may be an important strategy to prevent stunting in vulnerable settings.

Keywords
Stunting
Low birth weight
Complementary feeding
Breast-feeding
Iron-deficiency anaemia

Stunting affects approximately 159 million children under 5 years old worldwide and a greater proportion of these children are in sub-Saharan Africa and south-central Asia(1). Childhood stunting and micronutrient deficiencies are usually associated with poor nutrition and increased exposure to infections and unsanitary environments(2). In South Africa, stunting remains the most prevalent form of undernutrition in children under 5 years old(3). The results of the 2012 South African National Health and Nutrition Examination Survey (SANHANES) showed that stunting in South African children was highest in the age group of 0–3 years, 26·9 and 25·9 % for boys and girls, respectively(4).

In South Africa, malnutrition is often associated with sociodemographic factors, income level, weekly expenditure on food, employment status, education level of the mother and food insecurity(5). Complementary foods commonly consumed are usually cereal based and deficient in key micronutrients(6,7). This may result in increased risk of micronutrient deficiencies, resulting in a vicious cycle between malnutrition and infection that may be linked to the moderately high prevalence of stunting among South African children under 5 years of age(4).

The relationship between stunting and sociodemographic, household and environmental determinants is still not clearly understood. Intergenerational factors such as maternal short stature may increase the risk of poor offspring birth outcomes and growth retardation(8–10). Stunting begins *in utero* and is linked to maternal short stature(8–10) and poor maternal nutrition(2), resulting in intra-uterine growth restriction and low birth weight. This points towards the importance of interventions from preconception through the 1000 d window period to prevent the intergenerational cycle of stunting.

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There is a need to understand the interplay between several factors associated with stunting to develop and scale up population-, sex- and age-specific interventions, and help to encrypt the multifaceted causal matrix. Studies on factors associated with stunting among children under 5 years within an age range[7,8,11] have been published, but there is a lack of information about the prevalence and factors associated with stunting in specifically 6-month-old infants in developing countries. Therefore, the aim of the present study was to identify maternal, socio-economic, feeding practices and child characteristics associated with stunting among 6-month-old infants from a peri-urban area in South Africa. The data for the present study were collected as the baseline for a randomized controlled trial assessing the efficacy of lipid-based nutrient supplements on the growth of 6-month-old infants. The trial is registered (NCT01845610) at http://clinicaltrials.gov.

Methods

Study site, sampling and participants

The current paper presents data on the factors associated with stunting in 6-month-old black infants (n 750) using baseline data of a randomized controlled trial. The data were collected between September 2013 and January 2015 and the trial was carried out in the peri-urban area of Matlosana Municipality, North West Province of South Africa. Trained fieldworkers recruited potentially eligible mother–infant pairs through five primary health-care clinics and house-to-house visits. A total of 998 mother/caregiver–infant pairs were recruited, of whom 235 failed to come for the final screening visit and thirteen were excluded because they were not eligible to be included in the randomized controlled trial. The sample size (n 750) was based on sample size calculations for the randomized controlled trial, which had linear growth as the main outcome. The sample size was adequate for the cross-sectional analyses performed for the current study with the main aim to determine variables associated with stunting, assuming a probability of stunting of at least 0·2 and a minimum odds ratio of 1·3 (or 0·8 for an inverse association) at a type 1 error of 5 % and power of 80 %[12].

Inclusion and exclusion criteria

Black infants of age 6 months from a peri-urban area were enrolled in the study. Infants were excluded if they had never received any breast milk previously, had severe obvious congenital abnormalities, Hb < 70 g/l, weight-for-height Z-score < −3, other diseases or recent hospitalization, if their caregiver planned to move out of the study area within the next 7 months, if they were receiving special nutritional supplements as part of feeding programmes, were diagnosed with HIV infection (we did not test for HIV status in the study), were known be allergic/intolerant to peanuts, soya, cow's milk protein or fish, or they had not been born as a singleton. Infants were enrolled if they came with the parent(s) or caregiver; however, for assessing maternal height, only data from biological mothers were used.

Data collection, measurements and handling

Weight and recumbent length were taken according to WHO standardized techniques[13]. The anthropometry assessors were trained according to the WHO Training Course on Child Growth Assessment for infants[14]. Infants were undressed and weighed to the nearest 0·01 kg using a digital baby scale (model 354, maximum weight 20 kg; Seca GmbH & Co. KG, Hamburg, Germany). Recumbent length was measured to the nearest 0·1 cm using an infantometer (model 416; Seca). Mid-upper arm circumference was measured using a measuring tape (Seca 201) and head circumference was measured using a measuring tape (Seca 212). All measurements were done in duplicate and if the first two measurements differed by >0·05 kg for weight or by >0·2 cm for length or circumference, a third measurement was done, the two closest values were recorded and the means were calculated. The anthropometric indices, namely length-for-age Z-score (LAZ), weight-for-length Z-score (WLZ), weight-for-age Z-score (WAZ), head circumference-for-age Z-score (HCZ), BMI-for-age Z-score (BAZ) and mid-upper arm circumference-for-age Z-score (MUACZ), were generated using WHO Anthro 2005 software. Birth weight was obtained from the infant's Road-to-Health booklet.

The weight of mothers was measured to the nearest 0·01 kg using a digital adult scale (UC-321; Precision A&D Company, Ltd, Tokyo, Japan), while the height of the mothers was measured using a mechanical stadiometer (Seca, Birmingham, UK) according to standard methods[15]. The standard formula, [weight (kg)]/[(height (m)]^2, was used to calculate BMI[16]. The scales were calibrated on a daily basis.

A set of unquantified FFQ was used to assess dietary intake of the infants during the past week (7 d). Breastfeeding and complementary feeding practices were assessed based on a WHO questionnaire[17]. The questionnaire also had questions on sociodemographic characteristics, water and sanitation, and size of households, and education, employment status and marital status of mothers/caregivers.

Anaemia and iron status were analysed from blood samples (4 ml) which were collected via antecubital venepuncture into EDTA-coated trace-element-free evacuated tubes (Becton Dickinson, Franklin Lakes, NJ, USA) by the study nurse. In cases where obtaining a blood sample was not successful, a finger prick was performed to assess Hb status. Hb was determined for all infants (n 750) using a HemoCue machine (Ames Mini-Pak haemoglobin test pack and Ames Minilab; Bio Rad Laboratories (Pty) Ltd, Hercules, CA, USA). A blood sample was successfully obtained from 485 infants. Blood for later analyses was prepared by centrifuging at 500***g*** for 15 min at room temperature and aliquoted plasma was stored at –80°C in temperature-monitored freezers at North-West University (Potchefstroom, South Africa). For analysis, the samples were shipped to Vitmin Lab (Willstaett, Germany) as per shipment regulations and specifications of the National Department of Health. Plasma ferritin (PF) and soluble transferrin receptor (sTfR) concentrations were determined using a sensitive sandwich ELISA technique[18]. High-sensitivity C-reactive protein (CRP) and α_1-glycoprotein (AGP) were measured with an ELISA kit from Human Diagnostics (Wiesbaden, Germany).

Definitions

Anthropometric status was assessed using the WHO Child Growth Standards[19]. Wasting was defined as WLZ < −2, stunting as LAZ < −2, underweight as WAZ < −2 and overweight as WLZ > +2[20]. Low birth weight was defined as birth weight below 2·5 kg regardless of gestational age[21]. Maternal short stature was defined as height below 150·1 cm, which is the median minus 2 SD of the reference height for 18-year-old girls[22]. Anaemia was defined as Hb < 11 g/dl, iron deficiency (ID–PF) as PF <12 μg/l and iron-deficiency anaemia (IDA–PF) as both PF <12 μg/l and Hb < 11 g/dl[23,24]. ID–sTfR was defined as sTfR > 8·3 mg/l and IDA–sTfR was defined as both Hb < 11 g/dl and sTfR > 8·3 mg/l (test-kit reference value). Inflammation was detected by acute-phase proteins, AGP > 1 g/l and CRP > 5 mg/l[25]. Individual PF concentrations were adjusted by using correction factors specific to each individual's inflammatory status[25].

Statistical analysis

Shapiro–Wilk test and Q–Q plots were used to check for normality of the continuous variables. Results are reported as the mean and standard deviation for continuous normally distributed data, or as the median and interquartile range for continuous non-normally distributed data. The independent *t* test was used to test for significance of the difference between two means, the Mann–Whitney test for significance of differences between median values and the Pearson χ^2 test for associations between categorical data. Univariate logistic regression analysis was done to explore and understand the relationships between variables and stunting. Factors significantly associated with stunting were then included in the multivariable binary logistic regression analysis with stunting (stunted *v.* non-stunted) as the dependent variable using the backward elimination technique. The factors that were included in the regression models were sex, birth weight (kg), Hb (g/dl), sTfR (mg/l), AGP (g/l), education level of the mother/caregiver and consumption of jarred commercial infant foods. Maternal height (cm) was included in the final model based on theoretical evidence that the mother's stature influences birth outcomes and stunting[8,10]. Nagelkerke R^2 and the Hosmer and Lemeshow test were used to evaluate the goodness-of-fit of the model and as the basis for selecting the final model. The *P* value, odds ratio and 95 % confidence interval are reported for the respective regression coefficients. For all analyses, statistical significance was set at $P < 0·05$. In univariate logistic regression $P < 0·10$ was used as a cut-off point to retain variables in the regression model. The data were analysed using the statistical software package IBM SPSS Statistics version 23.

Results

A total of 750 infants (387 boys, 363 girls) with a mean age of 6·2 (SD 0·3) months participated in the study. Significantly more boys than girls were stunted (32·0 *v.* 24·8 %, $P = 0·028$). Low birth weight was recorded in 14·0 % of the infants and of these 58·8 % were stunted compared with 41·2 % who were not stunted. Sociodemographic and household characteristics compared by stunting status are presented in Table 1. The majority (91·7 %) of the women who participated in the study were the biological mothers of the infants and their mean age was 27·1 (SD 6·6) years. More than half of the mothers/caregivers (55·3 %) were not married and most (81·3 %) had at least 10 years of schooling (grade 10). Most households had at least one person employed and the median number of beneficiaries of social grants per household was 2 (interquartile range 1–3). The median size of households was 5 (interquartile range 4–7) people.

Breast-feeding and complementary feeding practices

Table 2 shows the summary of the mother/caregiver's feeding practices for their infants at age 6 months. Nine of the caregivers did not respond to the FFQ, as they were not the full-time caregivers. At age 6 months, 70·1 % of the infants were still being breast-fed, with breast milk being either the only milk feed or being given in combination with other milk feeds. Of the 750 infants, 5·9 % were exclusively breast-fed to the recommended age of 6 months.

Among the infants who were already consuming complementary foods (*n* 741), the mean age for introducing liquids and semi-solids was 2·5 (SD 1·7) months and 3·8 (SD 1·5) months, respectively. The liquids introduced first (*n* 713) were water (53·6 %), formula milk (39·1 %) and a variety of other liquids (rooibos tea, sweetened drink, sugar water, cow's milk; 7·3 %). The foods introduced first (*n* 701) were commercial infant cereal (63·8 %), jarred commercial infant foods (20·3 %), maize meal porridge (8·7 %) and other foods including sorghum porridge, oats porridge and vegetables (7·2 %). Milk feeds given to the infants at the age of 6 months were breast milk only (52·7 %), breast milk and formula milk (14·9 %), breast milk and cow's milk (2·4 %), formula milk only (27·7 %) and cow's milk only (1·1 %); while 1·2 % received no milk feeds. Foods that were frequently consumed (at least 4 d during the past week) were infant cereal (68·1 %), sugar (27·9 %) and jarred commercial infant foods (22·7 %). Other complementary foods eaten at least once during the previous week included vegetables (43·3 %), fruits (26·4 %), eggs (23·9 %), red meat (5·1 %), chicken (28·9 %), liver (10·5 %) and fish (2·7 %).

Table 1 Baseline sociodemographic and household characteristics and iron status, and comparison according to stunting, among infants aged 6 months from a peri-urban South African community, September 2013–January 2015

	Total (*n* 750)		Not stunted (*n* 536)		Stunted (*n* 214)		
	n	%	*n*	%	*n*	%	*P*†
Caregiver's relationship with infant							
Biological mother	688	91·7	488	91·0	200	93·5	0·749
Grandmother	32	4·3	26	4·9	6	2·8	
Aunt	21	2·8	16	3·0	5	2·3	
Father	6	0·8	4	0·7	2	0·9	
Caregiver not related	3	0·4	2	0·4	1	0·5	
Marital status of mother/caregiver							
Not married	415	55·3	298	55·6	117	54·5	0·328
Living together	212	28·3	143	26·7	69	32·2	
Married	80	10·7	61	11·4	19	8·9	
Common-law husband/wife	26	3·5	19	3·5	7	3·3	
Widower/widow	10	1·3	8	1·5	2	0·9	
Separated/divorced	7	0·9	7	1·3	0	0·0	
Level of education							
Higher than grade 10 (FET)‡	601	81·3	442	83·6	159	75·7	0·014*
Less than grade 10	138	18·7	87	16·4	51	24·3	
Tap water at home	719	95·8	513	95·7	206	96·3	0·626
Flush toilet at home	713	95·1	511	95·3	202	94·4	0·703
Electricity at home	692	92·3	502	93·7	190	88·8	0·024*
Iron and Inflammatory status							
Anaemic (*n* 750)§	274	36·5	177	33·0	97	45·3	0·002*
CRP > 5 mg/l (*n* 485)	72	14·8	50	14·3	22	16·3	0·577
AGP >1 g/l	156	32·2	104	29·7	52	38·5	0·063
ID–PF‖	78	16·1	50	14·3	28	20·7	0·083
ID–sTfR¶	146	30·1	92	26·3	54	40·0	0·002*
IDA–PF††	51	10·5	31	8·9	20	14·8	0·055
IDA–sTfR‡‡	71	14·6	41	11·7	30	22·2	0·003*

FET, further education and training; CRP, C-reactive protein; AGP, α_1-glycoprotein; ID, iron deficiency; PF, plasma ferritin; sTfR, soluble transferrin receptor; IDA, iron-deficiency anaemia.
The cut-offs for anaemia, ID and IDA were based on WHO standards(23).
*Significant at $P < 0·05$.
†*P* value from Pearson's χ^2 test.
‡FET corresponds to more than 10 years of schooling in South Africa.
§Anaemia defined as Hb < 11 g/dl.
‖ID–PF defined as PF <12 µg/l.
¶ID–sTfR defined as sTfR > 8·3 mg/l.
††IDA–PF defined as Hb < 11 g/dl and PF < 12 µg/l.
‡‡IDA–STfR defined as Hb < 11 g/dl and sTfR > 8·3 mg/l (*n* 485).

Anthropometric status of the infants and mothers

Results show that 28·5 % of the infants were stunted, 1·7 % were wasted, 11·1 % were underweight and 10·1 % were overweight. Mean anthropometric indices of the total group and comparison according to stunting status are presented in Table 3. Boys had significantly lower mean LAZ (–1·57 (SD 1·11) *v*. –1·31 (SD 1·02)) and HCZ (–0·05 (SD 1·05) *v*. 0·12 (SD 0·95)) than girls. Both sexes had relatively low LAZ and WAZ with reference to the WHO growth standards. Stunted infants had significantly lower *Z*-scores for all anthropometric indicators compared with the non-stunted infants.

Maternal weights and heights were obtained from 539/688 (78·3 %) biological mothers. The mean height was 156·8 (SD 6·05) cm. A total of seventy (13 %) mothers had short stature (height < 150·1 cm). Based on BMI, thirty-one (5·8 %) mothers were underweight, 201 (37·3 %) had normal weight, 165 (30·6 %) were overweight and 142 (26·3 %) were obese. There was no significant difference in the proportion of stunted infants for mothers of short stature *v*. normal stature (32·9 *v*. 26·9 %, $P = 0·296$). Although not statistically significant ($P = 0·118$), underweight mothers tended to have a greater proportion of stunted children (38·7 %) compared with normal-weight (31·3 %), overweight (26·1 %) and obese (21·8 %) mothers.

Anaemia and iron status of the infants

Table 1 also shows the prevalence of anaemia, iron deficiency and iron-deficiency anaemia in the study infants. In the present study boys had a higher prevalence of anaemia than girls (41·3 *v*. 31·4 %, $P = 0·005$). Stunted infants had a higher prevalence of anaemia than their non-stunted counterparts (45·3 *v*. 33 %, $P = 0·002$). Stunting was also associated with ID–sTfR ($P = 0·002$) and IDA–sTfR ($P = 0·003$), while there was a trend towards an association with iron deficiency based on ID–PF ($P = 0·083$) and IDA–PF ($P = 0·055$).

Logistic regression for the factors associated with stunting

The exploratory univariate analysis revealed that the factors significantly associated with stunting were low birth weight ($P < 0·001$), male sex ($P = 0·028$), education

Table 2 Feeding practices at 6 months of age, and comparison according to stunting, among infants aged 6 months from a peri-urban South African community, September 2013–January 2015

	Total (*n* 750)		Not stunted (*n* 536)		Stunted (*n* 214)		
Characteristic	*n*	%	*n*	%	*n*	%	*P*†
Age, cessation of exclusive breast-feeding							
0–2 months	367	48·9	268	50·0	99	46·3	0·361
3–4 months	271	36·1	194	36·2	77	36·0	
5–6 months	112	14·9	74	13·8	38	17·8	
Age, milk feeds introduced							
0–2 months	159	21·4	118	22·3	41	19·2	0·186
3–4 months	113	15·2	88	16·7	25	11·7	
5–6 months	67	9·0	46	8·7	21	9·8	
Not started	403	54·3	276	52·3	127	59·3	
Age, other liquids introduced							
0–2 months	342	45·6	248	46·3	94	43·9	0·644
3–4 months	253	33·7	183	34·1	70	32·7	
5–6 months	116	15·5	80	14·9	36	16·8	
Not started	39	5·2	25	4·7	14	6·5	
Age, semi-solid/solid foods introduced							
0–2 months	123	16·6	93	17·5	30	14·2	
3–4 months	326	43·9	227	42·7	99	46·9	0·464
5–6 months	249	33·6	182	34·3	67	31·8	
Not started	44	5·9	29	5·5	15	7·1	
Foods infants consumed (at least once in the previous week)							
Formula milk	352	47·5	262	49·5	90	42·5	0·081
Dairy foods‡	412	55·6	299	56·5	113	53·3	0·425
Jarred commercial infant foods	410	55·3	307	58·0	103	48·6	0·019*
Infant cereals	596	80·4	419	79·2	177	83·5	0·184
Maize meal porridge§	289	39·0	205	38·8	84	39·6	0·826
Fruits and vegetables‖	462	62·3	338	63·9	124	58·5	0·170
Animal-source foods¶	223	30·1	163	30·8	60	28·3	0·501
Sweetened cold drinks††	173	23·3	122	23·1	51	24·1	0·772
Fats‡‡	398	53·7	281	53·1	117	55·2	0·610

*Significant at $P<0·05$.
†P value from Pearson's χ^2 test.
‡Dairy foods: cow's milk and yoghurt.
§Maize meal porridge: home-prepared maize porridge and instant maize porridge.
‖Fruits and vegetables: fresh fruits and vegetables and fruit juice.
¶Animal-source foods: red meats, chicken, liver and fish.
††Sweetened cold drinks: fizzy drinks and dilutable drinks.
‡‡Fats: cooking oil and margarine used in preparing infant foods.

level less than grade 10 of the mother/caregiver ($P=0·014$), anaemia ($P=0·002$), ID–sTfR ($P=0·003$), underweight ($P<0·001$) and not consuming commercial jarred infant foods at least once during the preceding week ($P=0·020$; Table 4). These findings guided the development of a multivariable logistic regression analysis model. Maternal height was included in the final model as short mothers had significantly shorter infants (mean LAZ = –1·70 (SD 1·03)) compared with normal-height mothers (mean LAZ = –1·41 (SD 1·08); $P=0·033$).

The three models for the multivariable logistic regression analysis are summarized in Table 5. Model 1 includes all infants for whom the data for variables in the model were complete and was limited by the data for mother's height (*n* 518). Models 2 and 3 include sTfR and AGP, resulting in a smaller sample size (*n* 334, 44·5 %) due to low success with sampling of venous blood in this age group. The results based on model 1 show that boys were 1·73 times more likely to be stunted compared with girls (95 % CI 1·10, 2·70, $P=0·014$). Stunting showed an inverse relationship with both birth weight (kg; OR = 0·12; 95 % CI 0·07, 0·21, $P<0·001$) and maternal height (cm; OR = 0·94; 95 % CI 0·91, 0·98, $P=0·001$). There was a tendency for a negative association between consumption of jarred commercial infant foods and stunting (OR = 0·69; 95 % CI 0·44, 1·07, $P=0·099$). Hb (g/dl) and education level of the mother/caregiver showed no association with stunting ($P>0·05$) (Table 5, model 1). Model 3 shows that higher sTfR (mg/l) concentration was associated with higher odds for stunting and there was an inverse association between consumption of jarred commercial infant foods and stunting (Table 5).

Discussion

The results of the present study show that stunting affected almost a third (28·5 %) of the study population. This is of public health concern as there is evidence that stunting may result in poor cognitive and physical development, reduced productivity and increased risk of chronic diseases in adulthood[26]. Stunting was associated with

Table 3 Mean anthropometric indices, and comparison according to stunting, among infants aged 6 months from a peri-urban South African community, September 2013–January 2015

	Total (*n* 750)		Not stunted (*n* 536)		Stunted (*n* 214)		
	Mean	SD	Mean	SD	Mean	SD	*P*†
LAZ	−1·44	1·07	−0·94	0·75	−2·72	0·60	<0·001*
WLZ	0·54	1·15	0·62	1·15	0·33	1·13	0·002*
WAZ	−0·57	1·21	−0·16	1·06	−1·60	0·93	<0·001*
BAZ	0·37	1·19	0·52	1·18	0·01	1·15	<0·001*
MUACZ	0·25	1·09	0·51	1·03	−0·39	0·97	<0·001*
HCZ	0·03	1·00	0·28	0·92	−0·57	0·97	<0·001*

LAZ, length-for-age *Z*-score; WLZ, weight-for-length *Z*-score; WAZ, weight-for-age *Z*-score; BAZ, BMI-for-age *Z*-score; MUACZ, mid-upper arm circumference-for-age *Z*-score; HCZ, head circumference-for-age *Z*-score.
*Significant at $P<0{\cdot}05$.
†*P* value from *t* test.

Table 4 Factors associated with stunting at 6 months of age from univariate logistic regression analysis ($P<0{\cdot}1$) among infants from a peri-urban South African community, September 2013–January 2015

					95 % CI	
	B	SE	*P*†	OR	Lower	Upper
Male sex (boys)	0·36	0·16	0·028*	1·43	1·04	1·97
Wasted (WLZ < −2)	0·78	0·56	0·166	2·18	0·72	6·56
Underweight (WAZ < −2)	2·53	0·28	<0·001*	12·55	7·22	21·82
Low birth weight (<2·5 kg)	1·51	0·22	<0·001*	4·53	2·93	7·00
ID–sTfR (sTfR > 8·3 mg/l)	0·63	0·21	0·003*	1·87	1·23	2·84
Anaemia (Hb<11 g/dl)	0·52	0·16	0·002*	1·68	1·22	2·32
ID–PF (PF<12 μg/l)	0·45	0·26	0·085	1·57	0·94	2·62
Raised AGP > 1 g/l	0·39	0·21	0·064	1·48	0·98	2·25
Mother/caregiver education<10 years‡	0·49	0·20	0·014*	1·63	1·10	2·41
Maternal height<150·1 cm	0·29	0·28	0·297	1·33	0·78	2·28
Consumption of foods at least once during the previous week						
Fruits and vegetables	−0·23	0·17	0·170	0·80	0·58	1·10
Infant cereals	0·28	0·21	0·185	1·33	0·87	2·02
Jarred commercial infant foods	−0·38	0·16	0·020*	0·68	0·50	0·94
Formula milk	−0·29	0·16	0·082	0·75	0·55	1·04

WLZ, weight-for-length *Z*-score; WAZ, weight-for-age *Z*-score; ID, iron deficiency; sTfR, soluble transferrin receptor; PF, plasma ferritin; AGP, α_1-glycoprotein.
*Significant at $P<0{\cdot}05$.
†*P* value from univariate binary logistic regression analysis.
‡Education<grade 10 for mother/caregiver.

lower birth weight ($P<0{\cdot}001$), shorter maternal height ($P=0{\cdot}001$), male sex ($P=0{\cdot}017$) and higher sTfR concentrations (mg/l, $P=0{\cdot}021$; Table 5). These results support the notion that stunting is associated with poor maternal nutritional status and highlights the need for interventions to prevent the intergenerational origins of stunting.

Compared with the WHO cut-off values for public health significance[12], the observed prevalence of stunting (28·5 %), underweight (11·1 %) and wasting (1·7 %) indicate that chronic malnutrition is a problem of public health significance in this community. In a review paper, du Plessis *et al.*[27] concluded that the high level of stunting in South Africa is a consequence, in part, of poor breastfeeding and complementary feeding practices, and the poor quality of complementary diets. The observed 28·5 % stunting prevalence agrees with findings from the 2012 SANHANES, which found for children 0–3 years old that stunting prevalence for boys and girls was 26·9 and 25·9 %, respectively[4]. However, stunting at age 6 months and stunting over an age range of 0–3 years may not be directly comparable, because the prevalence of stunting has been shown to double within the first 2 years of life[28].

On the contrary, regional studies involving 6–12-month-old South African infants reported lower prevalence of stunting at 11 %[29], 16 %[30] and 13 %[27] in KwaZulu-Natal Province and 12 % in Eastern Cape Province[28]. Although these differences may be attributed partly to non-representativeness of the regional data, the observed stunting prevalence supports the view that the epidemiology of stunting varies within a country and between boys and girls. This was also reflected in the 2012 SANHANES data for children under 15 years of age, which showed that overall boys were more stunted than girls, and that the boys from North West Province (23·7 %), for example, had higher prevalence of stunting compared with those from KwaZulu-Natal (13·5 %) and Gauteng (11·9 %) provinces[4].

Logistic regression showed that birth weight (kg) was inversely associated with stunting ($P<0{\cdot}001$, Table 5). This is in line with previous findings and points towards the association between maternal undernutrition, low birth

Table 5 Summary of three multivariable binary logistic regression models for odds for stunting at 6 months of age among infants from a peri-urban South African community, September 2013–January 2015

	Model 1 (*n* 518)†					Model 2 (*n* 334)‡					Model 3 (*n* 334)‡				
Variable	*B*	SE	*P*§	OR	95 % CI	*B*	SE	*P*§	OR	95 % CI	*B*	SE	*P*§	OR	95 % CI
Sex (0 = girls, 1 = boys)	0·55	0·23	0·014*	1·73	1·10, 2·70	0·34	0·28	0·230	1·40	0·81, 2·43	0·36	0·28	0·197	1·43	0·83, 2·48
Birth weight (kg)	−2·09	0·26	< 0·001*	0·12	0·07, 0·21	−1·71	0·34	< 0·001*	0·18	0·09, 0·35	−1·72	0·34	< 0·001*	0·18	0·09, 0·35
Hb (g/dl)	−0·09	0·08	0·305	0·92	0·78, 1·08	–	–	–	–	–	–	–	–	–	–
Maternal height (cm)	−0·06	0·02	0·001*	0·94	0·91, 0·98	−0·05	0·02	0·024*	0·95	0·91, 0·99	−0·05	0·02	0·024*	0·95	0·91, 0·99
Education level of mother/caregiver (0 = > grade 10, 1 = < grade 10)	0·22	0·30	0·472	1·24	0·69, 2·23	0·38	0·36	0·284	1·47	0·73, 2·95	–	–	–	–	–
Consumption of jarred commercial infant foods‖ (0 = no, 1 = yes)	−0·38	0·23	0·099	0·69	0·44, 1·07	−0·55	0·28	0·051	0·58	0·33, 1·00	−0·61	0·27	0·025*	0·54	0·32, 0·93
sTfR (mg/l)	–	–	–	–	–	0·11	0·05	0·017*	1·12	1·02, 1·23	0·11	0·05	0·021*	1·12	1·02, 1·22
AGP (g/l)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Model goodness-of-fit															
R^2¶			0·293					0·243					0·239		
P††			0·652					0·051					0·212		

Conditional backward elimination was used to select variables. Dependent variable was stunting *v.* non-stunted.
*Significant at $P < 0·05$.
†Model 1: only 518/750 of the participants had complete data for all the variables included in the model.
‡Models 2 and 3 had a smaller sample size (334/750) with complete data for all the variables included in the model due to difficulty in obtaining blood samples for determination of iron deficiency (soluble transferrin receptor).
§*P* value from multivariable binary logistic regression analysis.
‖Consumption of jarred infant foods at least once in the previous week.
¶Nagelkerke R^2.
††*P* value from Hosmer and Lemeshow test.

weight and stunting in children[2]. Maternal short stature, combined with poor nutrition during preconception and pregnancy, may result in small birth size[11,31,32] and subsequent stunting in children[8–10]. Maternal short stature may therefore explain to some extent the observed 14·0 % low birth weight and 28·5 % stunting rates in our study. Although there is a need to address postnatal factors associated with stunting, evidence shows that, to prevent stunting, a stronger focus is needed on improving the prenatal environment in order to prevent intra-uterine growth restriction and the occurrence of low birth weight[33,34]. This highlights the importance of focusing on women of childbearing age to prevent growth faltering in children.

Multivariable logistic regression analysis showed that boys were 1·73 times ($P = 0·017$) more likely to be stunted than girls (Table 5), which concurs with the findings from sixteen Demographic and Health Surveys from ten sub-Saharan countries[35]. The most probable hypothesis explaining why boys are more vulnerable to stunting than girls is that it occurs already during pregnancy, with sex differences in fetal growth[36,37]. According to Di Renzo *et al.*, females have a selective advantage over males *in utero* which is associated with subsequent improved outcomes in the perinatal period; male sex is therefore an independent risk factor for small birth size and other adverse pregnancy outcomes[38]. One other plausible explanation for the higher odds of stunting in boys is that they are selectively more vulnerable to environmental infections, resulting in them having increased likelihood for neonatal morbidity compared with female infants[39]. Although these hypotheses may partly explain our findings, the underlying mechanisms that predispose boys to higher odds of stunting compared with girls are still poorly understood and speculative.

Infants with higher sTfR (mg/l) concentrations were 1·12 times more likely ($P = 0·021$) to be stunted than those with lower sTfR (mg/l) concentrations in logistic regression analysis (model 3, Table 5). The 30·1 % prevalence of iron deficiency based on sTfR observed in the present study may be a more accurate reflection of true iron deficiency, compared with the 16·0 % prevalence based on PF[25,40]. The coexistence of stunting and iron deficiency in the study infants may reflect underlying poor maternal nutrition[41]. Interventions aimed at preventing stunting should therefore also focus on preventing anaemia in young and pregnant women, coupled with promotion of breast-feeding and appropriate complementary feeding from age 6 to 23 months to maintain the infant's iron stores[2,42].

A significant number of infants were stunted (28·5 %), anaemic (36·4 %) and/or iron deficient (30·1 % based on ID–sTfR), despite the fact that the majority of infants consumed fortified infant foods. Receiving commercial jarred infant foods at the time of the survey was the only dietary factor that differed between stunted and non-stunted infants. However, in the multivariable binary logistic regression analysis, the negative association between consumption of commercial jarred infant foods and stunting was significant only in model 3 (Table 5), which was based on the smaller sample size (*n* 334). We acknowledge that consumption of specific complementary foods during the past week does not reflect early feeding practices. It should however be noted that that duration of exclusive breast-feeding ($P=0{\cdot}361$) and the age of introducing milk feeds ($P=0{\cdot}186$), other liquids ($P=0{\cdot}644$) and semi/solid foods ($P=0{\cdot}464$) did not differ between stunted and non-stunted infants (Table 2). At the age of 6 months, most infants have consumed a relatively small total amount of complementary foods and over a relatively short period. It is therefore unlikely that differences in complementary foods consumed could have affected linear growth in our study population.

The early use of commercial infant foods, as observed in the current study, has been previously reported for South African infants[4,5]. Early introduction of complementary foods explains the low exclusive breast-feeding rates (5·9 %) observed in our study, which is similar to the 2012 SANHANES findings of 7·4 % exclusive breast-feeding[4]. Siziba *et al.* reported 12 % exclusive breast-feeding in four of the nine provinces of South Africa[43]. The risk of mixed feeding over exclusive breast-feeding for infants younger than 6 months is an increased risk of infections, which in the long term may lead to stunting via the enteropathy mechanism[44]. In addition, stopping breast-feeding and introducing solids before 4 months increases the risk of obesity later in childhood[45]. Within the South African context of high HIV/AIDS prevalence and poverty, and high prevalence of obesity, efforts should be made to counter the strong cultural beliefs and other barriers to exclusive breast-feeding[46] as part of a stunting prevention strategy.

The cross-sectional nature of the present study limits ability to make inferences on causation. Other limitations include that the gestational age of infants could not be recorded accurately due to lack of information on health records. Gestational age is important in the interpretation of low birth weight[47,48], therefore the interpretation of low birth weight could have been compromised. Models 2 and 3 of the multivariate analysis are based on only 44·5 % of the total study sample for infants who had all variables included in the models. It is possible that these models in the multivariate analyses could be underpowered. Due to difficulty in obtaining blood samples, sTfR and PF values were available for only 485 (64·7 %) of the 750 infants. Therefore, all iron indicators presented herein except Hb can be considered exploratory. However, when comparing those with a blood sample (*n* 485) and those without a blood sample (*n* 266), no significant differences were observed for mother's height ($P=0{\cdot}678$) and sex distribution ($P=0{\cdot}619$), but there was a significant difference between the two groups for low birth weight (52·9 *v.* 47·1 %, $P=0{\cdot}012$).

Nevertheless, the present study contributes to the body of knowledge that shows the link between socio-economic factors, maternal factors, feeding practices and stunting in 6-month-old infants from vulnerable populations. Furthermore, the 10·1 % prevalence of overweight and 28·5 % prevalence of stunting indicate the presence of the double burden of malnutrition already during infancy and reflect the nutrition transition in South Africa. There is therefore a need for coordinated efforts and effective implementation of existing plans and strategies that focus on the 1000 d window of opportunity to prevent the long-term consequences of stunting without exacerbating the problem of overweight and obesity.

Conclusions

The current study showed that the prevalence of stunting (28·5 %) was of public health significance and was significantly associated with lower birth weight, shorter maternal height, male sex and being iron deficient (sTfR). Interventions that focus on improving preconceptual and maternal nutritional status, as well as early feeding practices, may be an important strategy to prevent stunting in infants in vulnerable populations to prevent the long-term consequences of stunting on cognitive, motor and physical development.

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human subjects were approved by the Ethics Committees of North-West University (NWU; approval number NWU-00001-11-A1) and the South African Medical Research Council (SAMRC; approval number EC-01-03/2012). After institutional ethical approval, the project was reviewed by local authorities. The provincial, district and community's approval to conduct the study was sought through an engagement process with relevant stakeholders. Written informed consent was obtained from the mother or legal guardian of the infant. This study reports baseline data of a randomized controlled trial that was registered at http://clinicaltrials.gov as NCT01845610.

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