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RESEARCH ARTICLE

One-year anthropometric follow-up of South African preterm infants in kangaroo mother care: Which early-life factors predict malnutrition?

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Abstract

Background: Preterm infants often have poor short- and long-term growth. Kangaroo mother care supports short-term growth, but longer-term outcomes are unclear.

Methods: This study analysed longitudinally collected routine clinical data from a South African cohort of preterm infants (born <37 weeks gestation) attending the outpatient follow-up clinic of a tertiary-level hospital (Tshwane District, South Africa) for 1 year between 2012 and 2019. At 1 year, small-for-gestational age (SGA) and appropriate-for-gestational age (AGA) infants were compared with regard to age-corrected anthropometric *z*-scores (weight-for-age [WAZ], length-for-age [LAZ], weight-for-length [WLZ] and BMI-for-age [BMIZ]) and rates of underweight (WAZ < −2), stunting (LAZ < −2), wasting (WLZ < −2) and overweight (BMIZ> + 2). Multiple regression analysis was used to investigate associations between maternal/infant characteristics and rates of underweight, stunting, wasting and overweight.

Results: At 1 year, compared with AGA infants ($n = 210$), SGA infants ($n = 111$) had lower WAZ (−1.26 ± 1.32 vs. −0.22 ± 1.24, $p < 0.001$), LAZ (−1.50 ± 1.11 vs. −0.60 ± 1.06, $p < 0.001$), WLZ (−0.66 ± 1.31 vs. 0.11 ± 1.24, $p < 0.001$) and BMIZ (−0.55 ± 1.31 vs. 1.06 ± 1.23, $p < 0.001$), despite larger WAZ gains from birth (+0.70 ± 1.30 vs. +0.05 ± 1.30, $p < 0.001$). SGA infants had significantly more stunting (34.2% vs. 9.1%; $p < 0.001$), underweight (31.2% vs. 7.2%; $p < 0.001$) and wasting (12.6% vs. 4.3%, $p = 0.012$), with no difference in overweight (4.5% vs. 7.7%, $p = 0.397$). In multiple regression analysis, birth weight-for-GA *z*-score more consistently predicted 1-year malnutrition than SGA.

Conclusion: Preterm-born SGA infants remain more underweight, stunted and wasted than their preterm-born AGA peers at 1 year, despite greater WAZ gains. Interventions for appropriate catch-up growth especially for SGA preterm infants are needed.

KEYWORDS
child growth, malnutrition, preterm infants, small-for-gestational age (SGA), stunting

INTRODUCTION

Infants born preterm and/or small-for-gestational age (SGA)—so-called 'small vulnerable newborns [1]'—are at risk of short-and long-term adverse outcomes, including poor growth throughout childhood [1–5]. While most appropriate-for-gestational age (AGA) preterm infants catch up to their term-born peers in weight and height, SGA infants more often remain small throughout childhood [2, 3, 5]. In low- and middle-income countries (LMICs), socio-economic and nutritional deprivation further exacerbate underweight, wasting and stunting in these infants [6–9]. Poor postnatal growth is detrimental to neurodevelopment in preterm infants, particularly in resource-constrained environments [9]. The deleterious effects of growth faltering, but also the neurodevelopmental benefits

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of catch-up growth, are particularly evident in SGA infants [9–12]. On the other hand, excessive early growth makes these infants particularly prone to obesity, metabolic syndrome and cardiovascular disease [11, 13–16]. Appropriate growth, therefore, must be adequate to support optimal neurodevelopment without compromising metabolic health through excessive weight gain.

The World Health Organisation (WHO) recommends kangaroo mother care (KMC) for all preterm and low birth weight infants [17]. Key components of KMC include constant mother-infant skin-to-skin contact, promotion of exclusive human milk feeding and continued skin-to-skin care after discharge [18]. Systematic reviews confirm that KMC supports better short-term growth in weight, length and head circumference (proportionately to daily KMC duration), while also improving morbidity, mortality and breastfeeding outcomes [18, 19]. Less is known about longer-term growth, although limited research from India and Colombia suggests that infants receiving KMC attain similar weight, height and head circumference at 6–12 months as infants receiving traditional incubator-based care [20, 21]. The South African Department of Health recommends KMC for all small and sick infants [22, 23] and it has been implemented in numerous settings [24, 25] However, local research on long-term infant outcomes after KMC discharge is lacking. While national preterm birth rates are unknown, a local study suggests up to 25% of infants may be born preterm (particularly at 34 to <37 weeks), and one in five infants are SGA [26], indicating a significant potential public health burden.

This research investigated first-year anthropometric outcomes (as weight-for-age, length-for-age [LAZ], weight-for-length and body mass index (BMI)-for-age *z*-scores and associated indicators of malnutrition) in a South African cohort of preterm infants who received early-life KMC. The outcomes of infants born SGA and AGA were compared, and various infant and maternal characteristics were investigated as possible predictors of 1-year anthropometric outcomes.

METHODS

Sampling

This study examined clinic records of preterm-born infants attending the post-discharge KMC follow-up clinic at a Baby-Friendly accredited tertiary-level academic hospital in Tshwane District (Gauteng Province, South Africa). The 1100-bed hospital primarily serves a low-income peri-urban African population. The KMC unit admits approximately 70 preterm infants per month, mostly from the hospital's own maternity unit and neonatal intensive care and high care units, with a small percentage from clinics and lower level hospitals in the catchment area. Preterm infants are discharged home soon as they are clinically stable and feeding orally; usually at <40 weeks post-menstrual age (PMA) and weighing <2 kg. Home KMC is encouraged, and infants visit the hospital's KMC outpatient clinic for regular follow-up (initially weekly to bi-weekly, increasing to 1- to 3-monthly) until the age of 9–12 months.

Power-driven reverse chronologic sampling was performed of infants born before 1 January 2019 (to exclude the effects of the COVID-19 pandemic). All infants born preterm (<37 weeks gestation), with a known birth weight and 1 year of follow-up data were eligible. Those with major anatomic abnormalities (e.g., hydrocephalus) and genetic conditions complicating growth (e.g., trisomies) were excluded. For statistical reasons, four large-for-gestational age infants were excluded.

A priori power calculations (G*Power v3.1.9.2; Heinrich-Heine-Universität, Düsseldorf) indicated 130 infants per group (SGA and AGA) to detect an effect size of 0.3 with $\alpha = 0.05$ and power = 80%. Each included infant was immediately classified as SGA or AGA to ensure adequate sample sizes per group. Initial sampling of 1788 records from 2018 to 2016 yielded 270 infants who met the inclusion and exclusion criteria (211 AGA and 59 SGA), all of whom were included. Additionally, records dating back to the clinic's inception in 2012 were screened to identify additional SGA infants; all 53 SGA infants who met the inclusion criteria were included in the study. Treatment and infant feeding policies had remained consistent during 2012–2019.

Data collection

Birth weight was measured in the maternity ward using electronic infant weighing scales, where pregnancy dating was uncertain, paediatric doctors estimated GA using the Ballard score. Birth information was copied to the paper KMC clinic record by medical doctors prior to KMC discharge. Clinic records were stored in a dedicated, restricted-access filing cabinet in the KMC ward.

Follow-up anthropometric measurements were taken by a single experienced hospital dietitian following KMC clinic protocols. Weight was measured naked, to 0.01 kg, using electronic infant weighing scales. Length was measured using a portable measuring mat, placed on a hard tabletop, with a rigid headboard and moveable footboard, and recorded to 0.1 cm. Head circumference was measured to 0.1 cm using a non-elastic measuring tape. Feeding information was collected and recorded by the dietitian, and medical examinations were conducted and recorded by the paediatric doctors.

Socio-demographic information, birth data, maternal medical conditions (classified according to WHO ICD10-PM categories [27]), infant medical information, infant feeding practices and anthropometric measurements were extracted from clinic records to Excel. Data were captured in duplicate, and discrepancies identified using EpiInfo v3.5.1 (2008, CDC, Washington DC). Anthropometry at birth, 50 weeks PMA, and the final clinic visit (≥1 year old) were used for this analysis.

Data preparation and analysis

Infant chronologic age (in days) was calculated electronically using birth- and visit dates. Corrected age was calculated as chronologic age minus the number of days of prematurity (=280 days minus GA at birth). Birth weight-for-GA *z*-score (BWZ) was determined using the INTERGROWTH-21st Newborn Size Standards [28] computer application (https://intergrowth21.tghn.org/newborn-size-birth/), and infants classified as SGA (birth weight < 10th percentile) or AGA (birth weight ≥ 10th but ≤90th percentile). Early weight growth was quantified as the change in weight-for-GA *z*-score from birth to 50 weeks PMA, using the INTERGROWTH-21st Postnatal Growth Standards for Preterm Infants [29] (https://intergrowth21.tghn.org/postnatal-growth-preterm-infants/). Anthropometry at 1 year was assessed using WHO Anthro software (http://www.who.int/childgrowth/software/en/). *Z*-scores for weight-for-age (WAZ), LAZ, weight-for-length (WLZ) and BMI-for-age (BMIZ) were calculated using corrected age, along with rates of underweight (WAZ < −2), stunting (LAZ < −2), wasting (WLZ < −2) and overweight (BMIZ> + 2) [30]. First-year weight growth (ΔWZ) was quantified by subtracting BWZ from the WAZ at 1 year. The proportion of infants with ΔWZ < −1, ΔWZ ± 1 and ΔWZ > +1 was calculated and compared.

Analyses were performed using R Statistical Software (version 4.1.2, 2020; R Foundation for Statistical Computing, Vienna, Austria). Continuous variables were assessed for normality using the Shapiro–Wilk test. Birth characteristics and 1-year anthropometry (*z*-scores, ΔWZ and rates of malnutrition) of SGA and AGA infants were compared using the independent *t*-test (normally distributed continuous variables), Mann–Whitney U test (non-normally distributed continuous variables) and Chi-square or Fisher's exact test (categorical variables).

Associations between birth and early life factors (i.e., exposure variables) and anthropometric indicators of nutrition at 1 year (i.e., outcome variables) were investigated using multiple regression analysis. Preliminary univariate analyses compared each exposure variable (maternal age, parity, gravidity, HIV status, antiretroviral drug use in pregnancy, maternal conditions, infant sex, GA at birth, BWZ, SGA status, twins, congenital heart conditions, breastfeeding status during KMC stay and change in weight-for-GA *z*-score up to 50 weeks GA) to each malnutrition outcome (underweight, stunting, wasting and overweight, as defined above). Exposure variables with significant associations to the outcome were included in multivariate models. Associations were expressed as odds ratios (ORs) with 95% confidence intervals. McFadden's R^2 was calculated as overall indicator of each model's predictive ability.

To investigate selection bias arising from including only infants who attended a full year of follow-up visits, the sampled infants were compared to 489 randomly selected excluded infants with <1 year's follow-up data. Maternal and infant birth characteristics, anthropometry at 50 weeks PMA and anthropometry at the last recorded visit were compared. Among non-included infants, those discharged from follow-up before 1 year (i.e., early discharge) and those that were not discharged (i.e., lost to follow-up) were also considered separately.

Ethical and legal considerations

Approval to conduct the study was obtained from the University of Pretoria Faculty of Health Sciences Research Ethics Committee (Protocol 227-2021) and the hospital (KPTH 23/2021). Data were processed anonymously.

RESULTS

Description of sample

Maternal ($N = 301$) and infant ($N = 321$) characteristics are described in Table 1, including comparisons between SGA ($n = 111$) and AGA ($n = 210$) infants and their mothers.

Noteworthy maternal characteristics include 21.3% HIV infection rate, 26.1% mothers ≥35 years old, and 30.0% mothers whose gravidity exceeded parity, suggesting previous pregnancy loss. Ethnicity was not recorded, but maternal surnames, recorded home languages and local demographics suggest the majority were Black African. The most prevalent infant conditions were neonatal jaundice (59.9%), respiratory distress syndrome (56.1%) and congenital heart conditions (31.2%, including 65 patent ducti arteriosus, 47 patent foramen ovale and 8 ventricular/atrial septum defects).

Comparisons showed that SGA infants had significantly lower birth weight and BWZ, and higher mean gestational age, rates of anaemia requiring transfusion and rates of congenital heart conditions, particularly patent ductus arteriosus (SGA 31.5%, AGA 14.3%, $p < 0.001$). Significantly more mothers of SGA infants were self-reported foreign nationals.

Anthropometric outcomes AT 1 year of age

The mean chronologic age of infants at the ≥1-year follow-up visit was 381 ± 19 days (12.6 ± 0.6 months), with a mean corrected age of 332 ± 23 days (10.9 ± 0.8 months). Infant anthropometry is detailed in Table 2, and the comparison between SGA and AGA infants is illustrated in Figure 1. At 1 year, SGA infants had significantly lower mean values for all anthropometric measurements (weight, length and head circumference) and *z*-scores (WAZ, LAZ, WLZ, BMIZ and HCZ), along with significantly higher rates of underweight, stunting and wasting. Rates of overweight and combined stunting and wasting did not differ significantly. Additionally, SGA infants had a larger mean gain in WAZ over the first year, (Figure 2) and a larger proportion of SGA infants gained >1 WAZ unit while a smaller proportion lost more than 1 WAZ unit.

TABLE 1 Maternal and infant characteristics at birth.

Characteristic	Total sample ($N = 321$)		AGA ($N = 210$)		SGA[d] ($N = 111$)		p-value: SGA vs. AGA
	N	Value	*N*	Value	*N*	Value	
Maternal age (years)[a] (Mean ± SD)	283	29.5 ± 6.6	193	29.6 ± 6.6	90	29.1 ± 6.6	0.476[g]
Maternal age ≤ 19 (*n* [%])		18 (6.4)		13 (6.7)		5 (5.6)	0.907[h]
Maternal age ≥ 35 (*n* [%])		74 (26.1)		51 (26.4)		23 (25.6)	0.992[h]
Maternal parity[a] (Median [IQR])	283	2 (1–3)	193	2 (1–3)	90	2 (1–3)	0.124[g]
Maternal gravidity[a] (Median [IQR])		2 (2–3)		2 (2–3)		2 (1–3)	0.102[g]
Gravidity > parity (*n* [%])		85 (30.0)		60 (31.1)		25 (27.8)	0.670[h]
Mother is a foreign national (self-report)[a] (*n* [%])	301	76 (25.2)	210	42 (20.0)	111	34 (30.6)	<0.001[h] ***
Maternal HIV infection[a] (*n* [%])	301	64 (21.3)	196	36 (18.4)	105	28 (26.7)	0.194[h]
Antiretroviral treatment[a] (*n* [%])	64		36		28		
Initiated before pregnancy		27 (42.2)		18 (50.0)		9 (32.1)	0.201[i]
Initiated during pregnancy		17 (26.6)		7 (19.4)		10 (35.7)	
Initiated after delivery		10 (15.6)		4 (11.1)		6 (21.9)	
Not recorded		10 (15.6)		7 (19.4)		3 (10.7)	
Maternal conditions[a] (*n* [%])	301		210		111		
Placenta, cord, membranes		13 (4.3)		9 (1.3)		4 (3.6)	>0.999[i]
Pregnancy conditions[b]		60 (19.9)		38 (18.1)		22 (21.0)	0.863[h]
Labour and delivery conditions		64 (21.3)		51 (24.3)		13 (11.7)	0.009[h] **
Medical and surgical conditions		115 (38.2)		72 (34.3)		43 (38.7)	0.553[h]
Infant sex (male) (*n* [%])	321	159 (49.5)	210	105 (50.0)	111	54 (48.6)	0.910[h]
Gestational age (weeks) (Mean ± SD)	321	32.8 ± 2.4	210	32.5 ± 2.4	111	33.3 ± 2.3	0.001[g] **
Birth weight (kg) (Mean ± SD)	321	1.64 ± 0.48	210	1.77 ± 0.46	111	1.39 ± 0.43	<0.001[g] ***
Birth weight *z*-score[c] (Mean ± SD)		−0.86 ± 1.04		−0.26 ± 0.61		−2.00 ± 0.69	<0.001[g] ***
Infant feeding in KMC ward (*n* [%])	321		210		111		
Mother's own breast milk		314 (97.8)		205 (97.6)		109 (98.2)	1.000[i]
Donor breast milk		6 (1.9)		3 (1.4)		3 (2.7)	0.420[i]
Commercial infant formula		9 (2.8)		8 (3.8)		1 (0.9)	0.171[i]
Infant haemoglobin at 0–5 days (Mean ± SD)	108	16.7 ± 2.5	83	16.7 ± 2.6	25	16.9 ± 2.3	0.757[k]
Twins	321	53 (16.5)	210	33 (15.7)	111	20 (18.0)	0.711[h]
Infant morbidities[e] (*n* [%])	321		210		111		
Neonatal jaundice		191 (59.5)		129 (61.4)		62 (55.9)	0.397[h]
Respiratory distress syndrome		180 (56.1)		116 (55.2)		64 (57.7)	0.766[h]
Congenital heart conditions[f]		100 (31.2)		54 (25.7)		46 (41.4)	0.006[h] **
Infant sepsis		61 (19.0)		35 (16.7)		26 (23.4)	0.187[h]
Other infant infections		35 (10.9)		23 (11.0)		12 (10.8)	1.000[h]
Anaemia requiring transfusion		29 (9.0)		12 (5.7)		17 (15.3)	0.008[h] **
Chronic lung disease		19 (5.9)		9 (4.3)		10 (9.0)	0.145[h]

Abbreviations: HIV, human immunodeficiency virus; IQR, interquartile range; KMC, kangaroo mother care.

[a]For maternal characteristics, $n = 20$ duplicates of mothers of twins were removed (thus $N = 301$; 196 AGA, 105 SGA).

[b]Maternal conditions classified according to WHO ICD10-PM categories [27]. Conditions of labour and delivery only include conditions other than preterm delivery, as preterm birth was an inclusion criterion for the study.

[c]Calculated using the INTERGROWTH-21ST Newborn Size Standards [28].

[d]Small-for-gestational age: birth weight < 10th percentile.

[e]Some infants had more than one concurrent morbidity.

[f]Includes patent ductus arteriosus ($n = 65$; 30 AGA, 35 SGA; $p < 0.001$), patent foramen ovale ($n = 47$; 30 AGA, 17 SGA; $p = 0.934$) and ventricular/atrial septum defects ($n = 8$; 3 AGA, 5 SGA; $p = 0.131$).

[g]Mann–Whitney U test.

[h]Chi-squared test.

[i]Fisher's exact test (one or more subgroup $n \leq 5$).

$^{**}p < 0.01$; $^{***}p < 0.001$.

TABLE 2 Infant anthropometric characteristics at 1 year of age.

Characteristic	Value/*z*-score (mean ± SD)			*p*-value: SGA vs. AGA
	Whole sample ($N = 321$)	AGA ($N = 210$)	SGA ($N = 111$)	
Chronologic age (days)	381 ± 19	383 ± 19	381 ± 19	0.272[c]
Corrected age (days)	332 ± 23	331 ± 23	333 ± 22	0.133[c]
Any breastfeeding at last visit (*n* [%])	181 (56.4%)	116 (55.2%)	65 (58.6%)	0.663
Early weight growth: WAZ gain from birth to ≤50 weeks PMA[e]	−0.23 ± 1.23	−0.37 ± 1.18	+0.02 ± 1.29	0.010[c] **
Weight (kg)	8.56 ± 1.42	8.91 ± 1.34	7.91 ± 1.35	<0.001[c] ***
Weight-for-age *z*-score[a]	−0.59 ± 1.36	−0.22 ± 1.24	−1.26 ± 1.32	<0.001[d] ***
Weight-for-length[b] *z*-score	−0.16 ± 1.31	+0.11 ± 1.24	−0.66 ± 1.31	<0.001[d] ***
BMI-for-age[a b] *z*-score	−0.09 ± 1.30	+0.16 ± 1.23	−0.55 ± 1.31	<0.001[d] ***
WAZ change: birth to 1 year (ΔWZ)	+0.28 ± 1.33	+0.05 ± 1.30	+0.70 ± 1.30	<0.001[d] ***
ΔWZ > +1	94 (29.3%)	52 (24.9%)	42 (37.5%)	0.005 **
−1 ≤ ΔWZ ≤ +1	176 (54.8%)	115 (55.0%)	61 (54.5%)	
ΔWZ < −1	51 (15.9%)	42 (20.1%)	9 (8.0%)	
Length[b] (cm)	71.3 ± 3.0	72.1 ± 2.7	69.9 ± 3.0	<0.001[d] ***
Length-for-age[a] *z*-score	−0.91 ± 1.16	−0.60 ± 1.06	−1.50 ± 1.11	<0.001[d] ***
Head circumference (cm)	45.4 ± 1.8	45.7 ± 1.62	44.9 ± 1.9	<0.001[c] ***
HC-for-age[a] *z*-score	+0.21 ± 1.28	0.43 ± 1.15	−0.21 ± 1.41	<0.001[c] ***
Indicators of malnutrition (*n* [%])				
Underweight[a]: WAZ < −2	50 (15.6%)	15 (7.2%)	35 (31.2%)	<0.001[f] ***
Stunting[a b]: LAZ < −2	57 (17.8%)	19 (9.1%)	38 (34.2%)	<0.001[f] ***
Wasting[b]: WLZ < −2	23 (7.2%)	9 (4.3%)	14 (12.6%)	0.012[f] *
Overweight[a b]: BMIZ > + 2	21 (6.6%)	16 (7.7%)	5 (4.5%)	0.397[f]
Stunting + Wasting	10 (3.1%)	4 (1.9%)	6 (5.4%)	0.103[g]

Abbreviations: BMIZ, body mass index-for-age *z*-score; HC, head circumference; LAZ, length-for-age *z*-score; WAZ, weight-for-age *z*-score; WLZ, weight-for-length *z*-score.
[a]All age-related *z*-scores calculated using corrected age.
[b]Length was only available for $N = 320$ infants ($n = 209$ AGA and $n = 111$ SGA).
[c]Mann–Whitney U test.
[d]Independent *t*-test.
[e]Calculated using the INTERGROWTH-21ST Postnatal Growth Standards for Preterm Infants [29].
[f]Chi-square test.
[g]Fisher's exact test (one or more subgroup $n \leq 5$).
*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

Multiple regression analysis

Univariate analysis identified several significant associations between exposure and outcome variables, some of which became non-significant when included alongside other variables in multivariate analysis. The OR for univariate and multivariate analyses is shown in Table 3.

In multivariate analysis, odds of underweight were significantly increased by maternal conditions of pregnancy, and decreased by higher BWZ and greater early WAZ gains. The odds of stunting were significantly increased by being SGA, and decreased by higher BWZ and greater early WAZ gains. Odds of wasting were significantly increased by infant congenital heart conditions and decreased by higher BWZ. Odds of overweight were only significantly increased by greater early WAZ gains. The multiple regression models for all the variables had low R^2 values ($R^2 = 0.084$–0.223) indicating poor ability to predict underweight, stunting, wasting and overweight at 1 year.

Assessment for selection bias

Comparison of included and non-included infants revealed some significant differences (Supplementary Table S1). Non-included infants had significantly higher gestational age (33.3 ± 2.4 vs. 32.8 ± 2.4 weeks, $p < 0.001$) and BWZ (−0.62 ± 0.94 vs. −0.86 ± 1.04, $p = 0.013$). The study sample had a higher proportion of SGA infants due to deliberate over-sampling; BWZ did not differ significantly when AGA and SGA infants were separated, though the difference in GA remained significant. Non-included infants additionally had higher rates of maternal HIV infection (29.7% vs. 21.8%, $p = 0.013$) and fewer congenital heart defects (24.7% vs. 31.2%, $p = 0.045$).

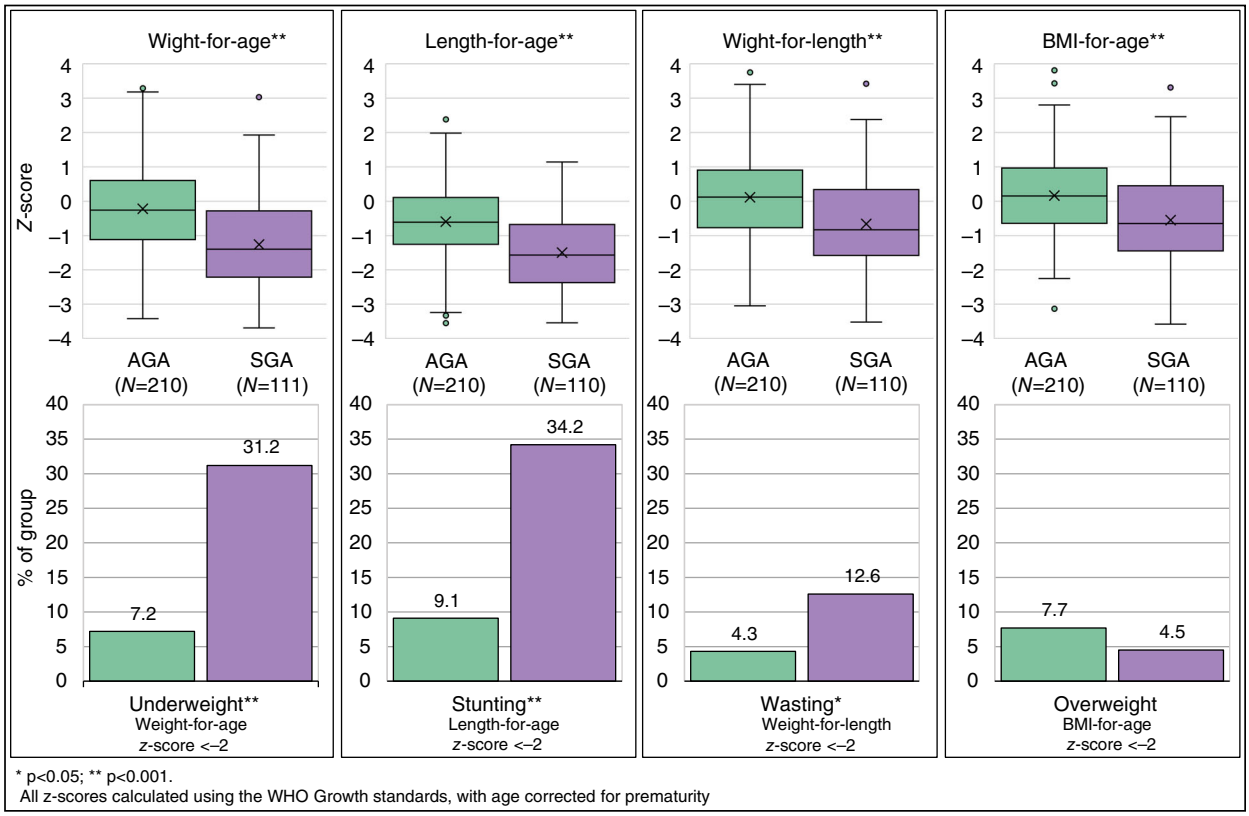

FIGURE 1 One-year anthropometric *z*-scores and rates of malnutrition in $N = 321$ small- and appropriate-for-gestational age infants.

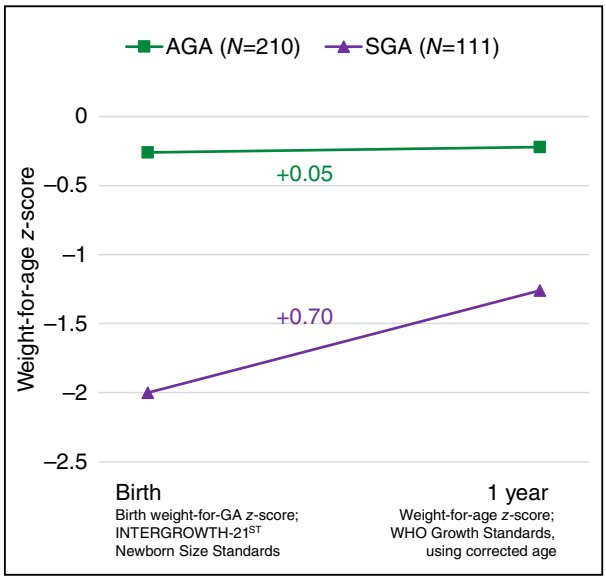

FIGURE 2 Change in weight-for-age *z*-score from birth to 1 year in $N = 321$ small- and appropriate-for-gestational age infants.

At the last recorded visit, non-included infants had significantly higher mean WLZ than included infants (+0.19 ± 1.24 vs. −0.16 ± 1.31, $p < 0.001$, with no significant difference between infants lost to follow-up and infants discharged early). Mean WAZ, LAZ, BMIZ or HCZ did not differ significantly between included and non-included infants, though infants discharged at <1 year had significantly higher WAZ (−0.21 ± 1.10 vs. −0.68 ± 1.36, $p = 0.011$) and LAZ −0.64 ± 1.24 vs. −1.13 ± 1.39, $p = 0.003$) than those lost to follow-up, with the study infants falling in-between (WAZ −0.59 ± 1.36, LAZ (−0.91 ± 1.16) (Table S2). Similar patterns were seen in SGA and AGA infants separately.

DISCUSSION

Birth weight and early weight growth were important predictors of 1-year anthropometric outcomes in this cohort of South African preterm infants with mixed health status, who received early KMC and close post-discharge follow-up with optimal support for nutrition and growth within the constraints of their socio-economic circumstances. The study infants and mothers had relatively high rates of co-morbidities (including maternal HIV, infant congenital heart conditions, respiratory distress syndrome, sepsis and other infectious illness), yet this is similar to recently published research in a comparable South African setting [24]. High rates of breastfeeding at KMC discharge (97.8%) and 1 year (56.4%, compared with national rates of 51.4% at 12–15 months [31]) attest to effective in- and outpatient breastfeeding support.

At 1 year old, SGA infants remained significantly smaller than AGA infants on all anthropometric measurements

TABLE 3 Multiple regression analysis: odds ratios (with 95% confidence intervals) for selected exposure variables in relation to underweight, stunting, wasting and overweight at 1 year in $N = 321$ preterm-born infants.

	Outcome							
	Underweight		Stunting		Wasting		Overweight	
Exposure	Univariate[a]	Multivariate	Univariate[a]	Multivariate	Univariate[a]	Multivariate	Univariate[a]	Multivariate
Maternal conditions of pregnancy[b]	2.43 (1.21, 4.73) ($p = 0.010$)	3.01 (1.34; 6.70) ($p = 0.007$)	–	–	–	–	–	–
Maternal conditions of labour/delivery[c]	0.31 (0.09, 0.79) ($p = 0.029$)	–	–	–	–	–	–	–
Infant congenital heart conditions	2.15 (1.15, 3.97) ($p = 0.015$)	–	–	–	4.68 (1.96, 12.0) ($p < 0.001$)	2.67 (1.02; 7.35) ($p = 0.049$)	0.22 (0.03, 0.76) ($p = 0.042$)	–
Birth weight *z*-score[d] (per 1 unit increase)	0.40 (0.28, 0.55) ($p < 0.001$)	0.45 (0.25; 0.78) ($p = 0.005$)	0.48 (0.35, 0.64) ($p < 0.001$)	0.61 (0.37; 0.99) ($p = 0.047$)	0.47 (0.32, 0.69) ($p < 0.001$)	0.42 (0.21; 0.81) ($p = 0.010$)	–	–
Being SGA[e]	6.72 (3.50, 13.55) ($p < 0.001$)	–	5.31 (2.91, 9.98) ($p < 0.001$)	2.99 (1.07; 8.65) ($p = 0.039$)	3.25 (1.38, 8.07) ($p = 0.008$)	–	–	–
Early weight-for-GA *z*-score change[f] (per 1 unit increase)	0.77 (0.60, 0.98) ($p = 0.035$)	0.60 (0.44; 0.80) ($p < 0.001$)	0.71 (0.56, 0.89) ($p = 0.004$)	0.58 (0.44; 0.75) ($p < 0.001$)	–	–	1.79 (1.21, 2.75) ($p = 0.005$)	1.73 (1.15; 2.70) ($p = 0.012$)
Model R^2 [g]	–	0.223	–	0.166	–	0.150	–	0.037

Note: '–' denotes no significant association.

[a]Univariate analysis found no significant relationships for maternal age, parity, gravidity, HIV, timing of ART initiation, maternal conditions of the placenta, cord or membranes, maternal medical and surgical conditions, infant sex, breastfeeding at last visit.

[b]Maternal conditions of pregnancy include incompetent cervix, preterm rupture of membranes, oligohydramnios/polyhydramnios, ectopic pregnancy, multiple pregnancy, malpresentation and other complications of pregnancy (excluding pregnancy-related medical conditions like hypertensive disorders, pre-eclampsia and gestational diabetes mellitus) [27].

[c]Maternal conditions of labour and delivery include breech delivery, malposition and disproportion during labour and delivery, forceps delivery/vacuum extraction, Caesarean delivery, spontaneous preterm labour, and other complications of labour and delivery [27].

[d]Birth weight *z*-score calculated using the INTERGROWTH-21ST Newborn Size Standards [28], used as continuous variable.

[e]SGA = small-for-gestational age (birthweight-for-GA < 10th percentile on the INTERGROWTH-21ST Newborn Size Standards [28]).

[f]Early change in weight-for-GA *z*-score: difference between weight-for-GA *z*-score at ≤50 weeks PMA and birth; calculated using the INTERGROWTH-21ST Postnatal Growth Standards for Preterm Infants [29], used as continuous variable.

[g]McFadden's R^2 values >0.4 indicate good predictive ability.

(weight, length and head circumference) and *z*-scores (WAZ, LAZ, WLZ, BMIZ and HCZ), with higher rates of underweight, wasting and stunting. The rates of underweight (15.6%) and wasting (7.2%) in the study sample far exceed the average South African prevalence (underweight 3.1% and wasting 2.8% in children 12–17 months [31]). This is not uncommon in preterm infants in LMICs [8]. SGA infants had much higher rates of underweight (31.2% vs. 7.2%) and wasting (12.6% vs. 4.3%) than AGA infants, despite significantly greater WAZ gains over the first year of life. Thus, catch-up growth in SGA infants is still incomplete at 1 year, and may never be completed if trends seen in other LMICs hold true [8].

Although this study lacked reliable birth length measurements to investigate catch-up length growth, the low mean LAZ in SGA and AGA infants alike is concerning, particularly as length growth in the first 2 years predicts adult height and lifelong educational achievement [32]. Though the overall stunting rate in the sample (17.1%) is lower than the South African population prevalence (31.4%) in children 12–17 months [31], the SGA group had a very high stunting rate (34.2%). This suggest a prenatal length growth deficit that is not recovered in infancy. Recent research from various LMICs have similarly found that birth LAZ strongly predicts LAZ and stunting in the first 1–2 years of life. [33, 34] Thus, optimising foetal growth and preventing preterm birth are key. A recent systematic review identified numerous interventions for reducing preterm birth and/or SGA, including routine multiple micronutrient supplementation and targeted low-dose aspirin to prevent pre-eclampsia [35]. Furthermore, pre-pregnancy and/or prenatal maternal nutrition supplementation were found to increase birth length [34]. Incorporating these interventions in standard antenatal care services could potentially impact rates of preterm and SGA birth and, by extension, reduce childhood malnutrition and its sequelae.

Though this sample contained few overweight children, childhood overweight is an increasing problem in South Africa, occurring in 12.6% of children 12–17 months old [31]. High rates of obesity in adults, existing alongside chronic malnutrition, reflect the nutrition transition taking place in the country [31]. This so-called double burden of malnutrition has been associated with intergenerational cycles of maternal-foetal malnutrition: short maternal stature strongly predicts low birth weight and SGA, which in turn leads to childhood stunting. This, combined with later overnutrition (often against a backdrop of lifelong micronutrient undernutrition) leads to co-existing stunting and overweight in the new generation, which perpetuates the cycle [36].

Multiple regression analysis revealed that smaller size at birth and lower early weight growth were the most important predictors of poor anthropometric outcomes at 1 year. While BWZ and SGA were both independently associated with undernutrition (underweight, stunting and wasting), SGA became non-significant when included in multivariate analyses to predict underweight and wasting. This underscores the importance of accurate birth weight-for-GA assessment even in AGA infants: undernutrition occurred at 4.3%–9.1% in the AGA infants, but none in infants with BWZ > +0.7, suggesting that the association may be less important at higher BWZ.

Greater early weight growth (operationalised as change in weight-for-GA *z*-score up to 50 weeks GA) was associated with significantly lower odds of underweight and stunting, but increased odds of overweight. There is no clear guideline for the range of weight gain associated with either under- or over-nutrition, since the range of changes in weight-for-GA *z*-score in infants with stunting (−3.9 to +1.8) and overweight (−2.1 to +1.8) overlapped almost entirely. This highlights the importance of monitoring length alongside weight in routine growth monitoring and assessing weight in relation to length.

Two other conditions significantly predicted undernutrition: maternal conditions of pregnancy (for underweight) and infant congenital heart conditions (for wasting). Though congenital heart conditions were also significantly associated with underweight and overweight in univariate analysis, these associations became non-significant in multiple regression models. This is likely due to the association between BWZ and congenital heart conditions (evidenced by the high occurrence of these conditions in SGA infants). Additionally, cardiac lesions only affect infant growth if there is significant hemodynamic impairment [37, 38]. Such lesions were not evident in this sample, as none of the infants had evidence of cardiorespiratory failure and only one required surgical intervention.

Surprisingly, breastfeeding status did not predict malnutrition at 1 year. Other studies have found higher rates of breastfeeding difficulties in preterm and/or SGA infants, associated with higher rates of underweight at 6 months [39]. In this sample, intensive in-hospital and post-discharge breastfeeding support may have mitigated these risks. Additionally, study infants transitioned to complementary foods several months before the final visit, which further confounds the association. Future studies would benefit from more detailed dietary assessment.

An important limitation of the sampling design is the possibility of selection bias, as infants with specific characteristics may be discharged earlier, fail to attend clinic visits or be lost to follow-up for other reasons (e.g., hospital admission or death). Indeed, there were some differences between the study sample and non-included infants. The study infants had lower mean gestational age, which could conceivably affect early neonatal morbidity and growth. However, the mean differences were fairly small (0.39–1.03 weeks), and their relevance at 1 year of age is questionable. The non-included infants had a higher mean WLZ (but not BMIZ) at the last visit, particularly in SGA infants, suggesting the study may have included thinner infants. Differences in WAZ, LAZ and WLZ at last visit further suggest that the non-included infants who were discharged before 1 year exhibited better growth than the study sample, while infants who were lost to follow-up either exhibited poorer

growth than the study sample or were lost to follow-up before substantial catch-up growth was achieved.

The limitations of using routine clinical data must be acknowledged. Quality control during data collection may have been less stringent than in a research setting, although the use of a single experienced dietitian would improve the reliability of anthropometric measurements. Similarly, clinical records may have been incomplete, particularly with regards to maternal comorbidities, leading to underestimation of some conditions.

Future studies should pursue longer follow-up (to 2 years and beyond) to investigate the full extent of catch-up growth, and particularly the evolution of stunting and overweight rates over time. The role of complementary feeding practices in growth also warrants further study. Assessment of alternative outcomes such as body composition, neurodevelopment and cardiometabolic risk factors would further elucidate the impact of early-life growth patterns on long-term health. Context-specific feasibility and cost-effectiveness studies for evidence-based interventions to prevent preterm and SGA births should also be prioritised.

In clinical practice, early identification of infants at risk of poor growth is key, including preterm and/or SGA infants and those with poor early weight growth. Assessment of size at birth requires reliable estimates of gestational age as well as accurate measurement and plotting of weight and length. In infancy, length should be routinely measured (and weight-for-length assessed) to identify faltering linear growth and avoid overfeeding shorter children who then become overweight. Though LAZ and WLZ growth charts are incorporated in the South African patient-held Road-to-Health booklet, the skills, equipment and human resources to use them are often lacking [40–42]; this needs to be urgently addressed. Finally, in the South African context, replacing routine antenatal iron and folate supplementation with multiple micronutrients should be considered. Early attendance of antenatal care is also important, not only for early identification of complications but also for accurate pregnancy dating, and to ensure each infant has the best possible start in life.

CONCLUSION

Size at birth, particularly birth weight-for-GA, remains an important predictor of anthropometric outcomes in the first year of life. Even with early KMC and close post-discharge follow-up, preterm-born SGA infants have significant anthropometric deficits and high rates of undernutrition at 1 year, which may impact long-term well-being. Although SGA infants showed evidence of partial weight catch-up, LAZ remained low in both SGA and AGA infants, increasing their long-term risk of stunting and overweight. Mitigating these adverse outcomes will require a three-pronged approach: prevention of preterm birth and SGA, appropriate growth monitoring (including assessment of length and weight-for-length) and effective interventions to support appropriate postnatal catch-up growth in SGA preterm infants.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The datasets generated and analysed during the current study are available from the corresponding author on reasonable request.

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