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Research Article

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A Follow-up Study on Physical Growth and Motor Development in Small-for-Gestational-Age Infants

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Background： Small for gestational age (SGA) infants are the high-risk population that need to be paid more attention. The objective of this study was to investigate the patterns of physical growth and motor development in small for gestational age infants during the first two years of life.

Methods： A total of 158 SGA infants born between January 2018 and December 2022, who were regularly registered at the Child Health Development Center of Peking University Third Hospital, were enrolled. Body weight, length, head circumference, Peabody Developmental Motor Scales, feeding patterns, and catch-up growth status were assessed at approximately 3, 6, 9, 12, 18 and 24 months of age. Corrected age was used for preterm infants.

Results： Overall, 87.3% of SGA infants achieved successful catch-up growth within the first two years of life. SGA infants showed an uneven pattern of physical growth, with relatively more pronounced catch-up in head circumference, and a faster early weight gain compared to length gain. The catch-up patterns for different anthropometric indicators and at different months of age differed between preterm and term SGA infants. Preterm SGA infants exhibited more rapid catch-up in weight and length in the early period, whereas term SGA infants demonstrated more prominent long-term catch-up growth in head circumference. Analysis of factors influencing catch-up growth revealed that maternal diabetes during pregnancy affected the occurrence of catch-up growth in SGA infants. Multivariate logistic regression analysis indicated that fortified breast milk feeding at 3 months (aOR=3.890, 95%CI: 1.103~13.721) and 6 months (aOR=10.432, 95%CI：1.812~60.052，P=0.009) was associated with catch-up growth in SGA infants. Gross motor quotient and total developmental quotient exhibited a nonlinear trend of initial decline followed by an increase, with the lowest point occurring around 12 months of age.

Conclusion： The physical growth trajectory and motor development of SGA infants have distinct characteristics. Fortified breast milk feeding was associated with catch-up growth. 12 months of

age may be a critical time point for motor-development surveillance, especially females and those born to GDM-complicated mothers.The underlying mechanisms require further investigation, and validation through multicenter, large-sample studies is needed.

KEYWORDS:

small-for-gestational-age, physical growth, motor development, catch-up growth, fortified breast milk

1 Introduction

Small for gestational age (SGA) infants refer to neonates whose birth weight and/or birth length is below the 10th percentile for the same gestational age and sex [1]. This population represents a high-risk group requiring focused attention. SGA has been confirmed to be associated with an increased risk of type 2 diabetes and cardiometabolic diseases in early adulthood [2], and subsequent physical growth and motor development directly affect neurological, cognitive, and emotional health outcomes in children and adults [3]; therefore, it warrants significant attention. Most SGA infants spontaneously achieve catch-up growth (CUG) within the first two years of life; however, approximately 20% fail to do so, leading to short stature in adulthood [4–5]. SGA is also associated with an increased risk of adverse perinatal outcomes, including stillbirth, neonatal death, and admission to the Neonatal Intensive Care Unit (NICU) [6–9]. In this study, we established a birth cohort of SGA infants at our hospital and employed an observational cohort study design to preliminarily investigate physical growth and motor development at different time points from 0 to 2 years of age, the status of catch-up growth, and the impact of different feeding modalities on catch-up growth, thereby providing a reference for early postnatal growth monitoring in SGA infants.

2 Methods

2.1 Study subjects

SGA infants born at Peking University Third Hospital between January 1, 2018, and December 31, 2022, who were regularly followed up at the Child Health Development Center,

were enrolled. Inclusion criteria: (1) Birth weight below the 10th percentile for the same gestational age and sex (assessed according to the 2013 Fenton growth chart [10]); (2) Regular follow-up at the Child Health Development Center for at least two visits. Exclusion criteria: Diagnosis of severe congenital anomalies, genetic diseases, receipt of surgical procedures, or death during the birth or follow-up period.

This study was an observational cohort study. For preterm infants, corrected age was calculated by subtracting the number of weeks born before 40 weeks of gestation from chronological age. Follow-up time points were defined according to corrected age for preterm infants and chronological age for term infants. As the follow-up times at the Child Health Development Center varied among infants, the follow-up time points were defined based on the corrected age for preterm infants and the actual age for term infants as follows: birth, 3 months, 6 months, 9 months, 12 months, 18 months, and 24 months.A flowchart detailing participant selection and longitudinal follow-up is presented in Figure 1. This study was approved by the Medical Science Research Ethics Committee of Peking University Third Hospital (Ethics Approval No.: IRB00006761-M2024256). Participants were all children under 16 years of age, and informed consent for participation was obtained from their parents or legal guardians.

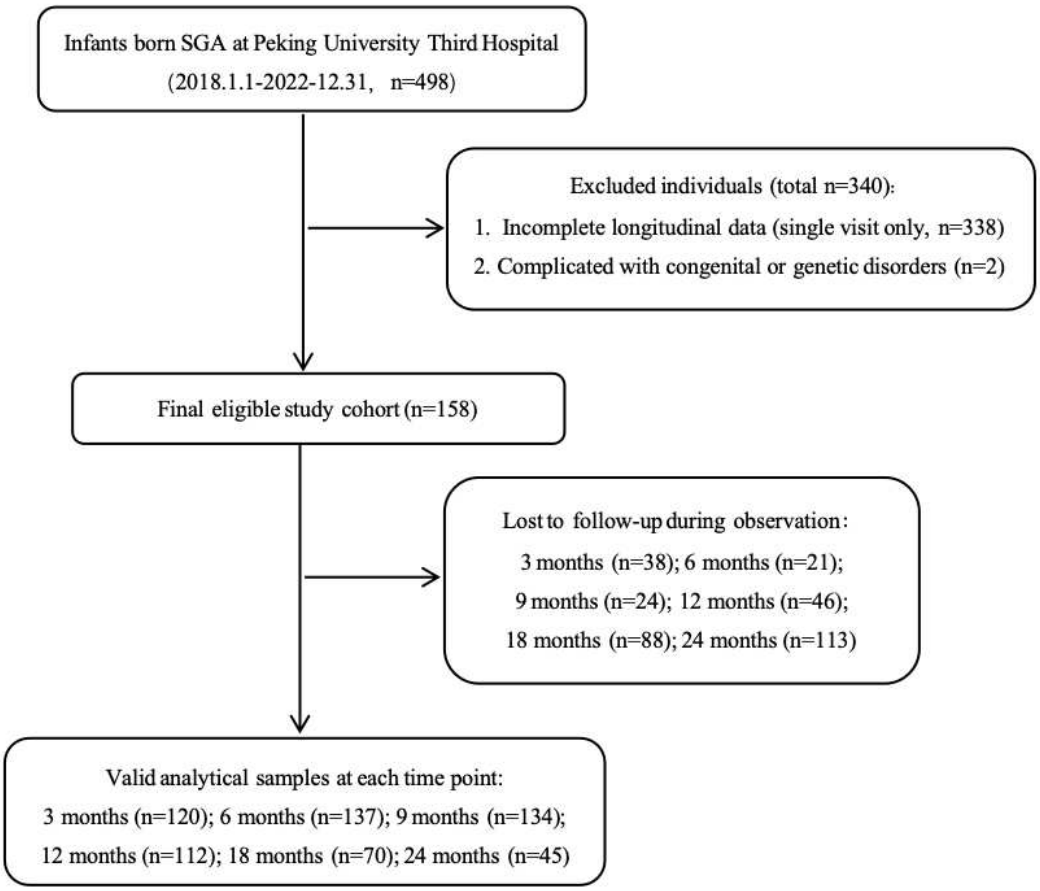


Figure 1 Flow chart of participant selection according to the STROBE statement

2.2 Data collection

2.2.1 Anthropometric measurements and assessment of catch-up growth

Body length and weight were measured using a specialized measuring tape and an infant weight scale, respectively. Head circumference was measured using a dedicated head circumference tape. A change in weight, length and head circumference Z-score > 0.67 was defined as weight, length and head circumference catch-up growth [11]. Z-scores were calculated using age- and sex-specific reference values. For example, weight catch-up growth was defined as an increase in weight-for-age Z-score of more than 0.67 from birth to the corresponding follow-up time point[12]. Body weight was used as the main reference index for catch-up growth.

2.2.2 Motor development assessment

Motor development was assessed by trained evaluators using the Peabody Developmental Motor Scales, Second Edition (PDMS-2), yielding the gross motor quotient (GMQ), fine motor quotient (FMQ), and total developmental quotient (TDQ). Scores < 80 were classified as poor, 80–

120 as average, and > 120 as superior [13].

2.2.3 Feeding patterns classification

Feeding patterns were classified into four categories: breastfeeding, formula milk feeding, mixed feeding, and fortified breast milk feeding. Mixed feeding was defined as a combination of breast milk and formula milk, with the amounts of breast milk and formula milk being roughly equivalent. Fortified breast milk feeding was defined as breastfeeding supplemented with fortifiers to increase nutrient content and energy intake.

2.3 Statistical analysis

Statistical analysis was performed using SPSS version 27.0. Continuous variables were described as mean ± standard deviation ($\bar{x} \pm SD$), and comparisons between groups at the same follow-up time point were performed using the t-test. Categorical variables were described as frequencies (percentages), and comparisons between groups were performed using the chi-square (χ^2) test or Fisher's exact test. Continuous variables not normally distributed were described as median and interquartile range (IQR, the 25th–75th percentiles); Nonparametric tests were used for between-group comparisons and comparisons of ordinal data. Two-way repeated measures ANOVA was used to analyze the longitudinal catch-up growth trajectories of preterm and term SGA infants over time. Adjusted odds ratios (aORs) and 95% confidence intervals (CIs) were calculated using multivariable logistic regression models. Multiple imputation sensitivity analysis was further performed to verify the robustness of the conclusions. Finally, a linear mixed model (LMM) incorporating various covariates was applied to analyze the nonlinear trends in motor development indicators over time. Model fitness was compared via -2 log-likelihood, Akaike information criterion (AIC), Bayesian information criterion (BIC), and likelihood ratio test (LRT). P value < 0.05 was considered statistically significant.

3 Results

3.1 Participant characteristics

Between January 1, 2018, and December 31, 2022, a total of 498 SGA infants were born at Peking University Third Hospital. Among them, 160 had regular follow-up at the Child Health

Development Center for at least two visits. After excluding 2 SGA infants (one diagnosed with Prader-Willi syndrome and one with a microdeletion on chromosome 6), a total of 158 SGA infants were included in the analysis. As shown in Table 1, the cohort comprised 81 males (51.3%) and 77 females (48.7%); 87 were preterm SGA (55.1%) and 71 were term SGA (44.9%). The median gestational age at birth was 37.3 weeks for term SGA and 34 weeks for preterm SGA. Forty-four mothers (27.8%) conceived via assisted reproduction, and 22.2% of the infants were twins. Regarding pregnancy complications, 48.7% of mothers had hypertension or hypertension-related disorders; 32.9% had diabetes or gestational diabetes mellitus; and 44.9% of the fetuses had fetal growth restriction. Ultimately, 87.3% of the SGA infants achieved successful catch-up growth within the first two years of life.

Table 1 General characteristics of the study population at baseline (n=158）

	Total(n=158)	Full-term(n=71)	Preterm(n=87)	P value
Sex				
Boys	81（51.3）	30（42.3）	51（58.6）	0.041
Girls	77（48.7）	41（57.7）	36（41.4）	
Gestational age at birth(weeks)	36.30 （ 34 ， 37.20）	37.30(37, 38.20)	34 (32, 35.20)	＜0.001
Birth weight (kg)	1.86 （ 1.44 ， 2.26）	2.29(2.02, 2.42)	1.51(1.15, 1.80)	0.008
Birth height (cm)	43（40，46）	45.70(44, 48)	40(37, 42)	＜0.001
Birth head circumference (cm)	30.75（29，32）	32(31, 33.5)	29.5(27, 30.5)	＜0.001
Assisted reproduction, yes	44（27.8）	18（25.4）	26（29.9）	0.527
Twins, yes	35（22.2）	7（9.9）	28（32.2）	0.001
Hypertension disorders of pregnancy, yes	77（48.7）	20（28.2）	57（65.5）	＜0.001

Gestational diabetes mellitus, yes	52（32.9）	19（26.8）	33（37.9）	0.137
Liver and kidney diseases, yes	12（7.6）	4（5.6）	8（9.2）	0.401
Placental abnormalities, yes	23（14.6）	13（18.3）	10（11.5）	0.227
Umbilical cord abnormalities, yes	21（13.3）	12（16.9）	9（10.3）	0.227
Maternal anaemia, yes	10（6.3）	4（5.6）	6（6.9）	0.746
Thyroid dysfunction, yes	21（13.3）	9（12.7）	12（13.8）	0.490
Fetal growth restriction, yes	71（44.9）	23（32.9）	48（55.2）	0.005
Catch-up growth(weight), yes	138（87.3）	63（88.7）	75（86.2）	0.635

*Values presented in this table are medians, IQR, numbers and percentages.

3.2 Follow-up of anthropometric indicators and analysis of factors associated with catch-up growth

3.2.1 Physical growth status at each follow-up time period

The average trends in weight, length, head circumference, and BMI of SGA infants at each follow-up period are shown in Figure 2. The standard growth values and standardized growth curves for children's weight, length, head circumference, and BMI at corresponding time points were used as normal reference values [14]. At birth, the weight, length, and head circumference of both male and female SGA infants were significantly lower than the WHO-0SD standard, with baseline levels approaching −2 to −3 SD. After 24 months of follow-up, all indicators in SGA infants showed significant catch-up growth, but the degree of catch-up varied: after 12 months of

age, male SGA infants approached the WHO-1SD level, while female SGA infants fell within the WHO-1SD to 0SD range, still not reaching the mean of the normal population. Length exhibited a similar trend. Head circumference showed the most pronounced catch-up effect, with female SGA infants approaching the WHO-0SD level at 12, 18, and 24 months of age. The BMI of SGA infants increased rapidly during the first 12 months after birth, with the peak approaching WHO-0SD, after which BMI gradually decreased and returned to around WHO-1SD by 24 months of age, suggesting that the rate of weight gain in early infancy exceeded that of length gain. Overall, the catch-up growth of SGA infants was relatively uneven.

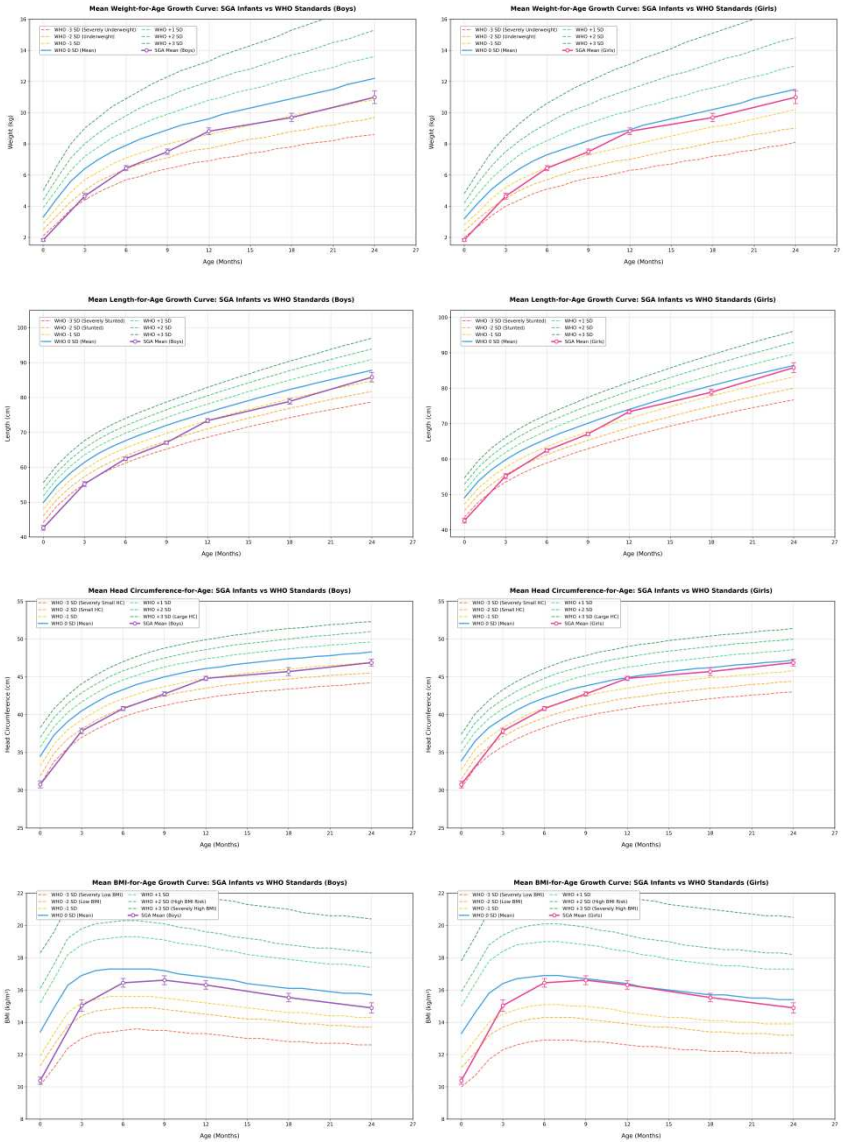


Figure 2 Trends in weight, length, head circumference, and BMI in SGA infants at each follow-up time period (compared with WHO growth curve standards)

3.2.2 Catch-up growth trajectories of preterm and term SGA infants

Figure 3 illustrates the longitudinal catch-up growth trajectories of weight, length, and head circumference Z-scores from birth to 24 months of age in preterm and term SGA infants. Two-way repeated measures ANOVA was used to analyze the differences between the two groups. For weight Z-scores, the main effect of time was significant ($F = 90.966$, $P < 0.001$), indicating an overall catch-up growth trend in weight after birth in both groups. The main effect of group was not statistically significant ($F = 1.459$, $P > 0.05$). The group × time interaction effect was significant ($F = 9.549$, $P < 0.05$), indicating that the weight catch-up growth trajectories differed significantly between preterm and term SGA infants. Simple effects analysis revealed that preterm SGA infants exhibited a faster rate of weight catch-up in the early postnatal period (0 – 6 months), whereas term infants showed a plateau in growth after 6 months of age with a slight surpassing of the preterm group. For length Z-scores, both the main effect of time and the group × time interaction effect were statistically significant (both $P < 0.05$), while the main effect of group was not statistically significant. Preterm SGA infants demonstrated a marked advantage in length catch-up during the first 12 months, and their length development at 24 months was slightly superior to that of term SGA infants. For head circumference Z-scores, the main effects of time and group, as well as the group × time interaction effect, were all significant (all $P < 0.05$). Term SGA infants showed a significant long-term advantage in head circumference catch-up, whereas preterm infants exhibited only a short-term catch-up in the early period, with head circumference Z-scores at 24 months remaining significantly lower than those of the term group.

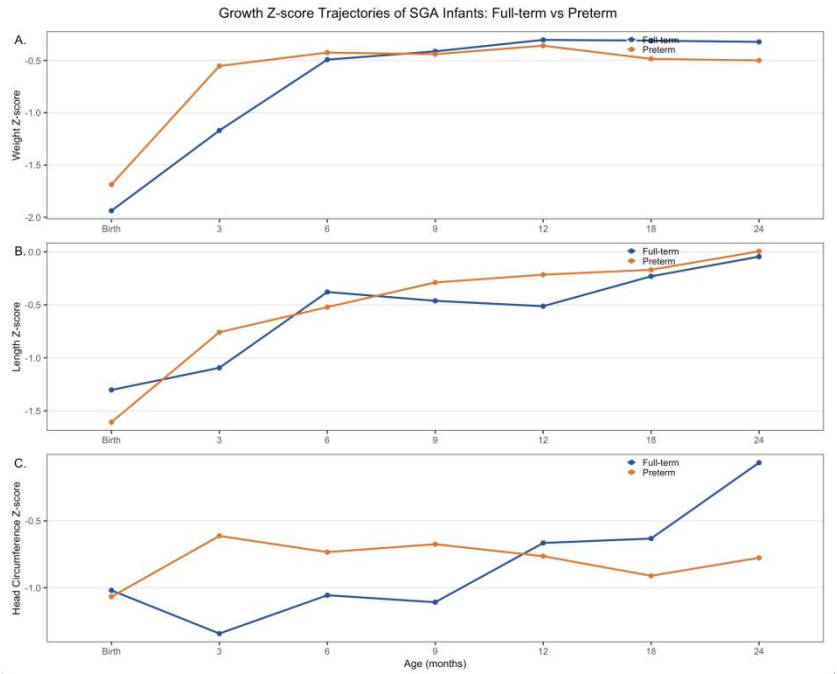


Figure 3 Growth Z-score trajectories of weight, length and head circumference from birth to 24 months in full-term and preterm SGA infants

3.2.3 Factors associated with catch-up growth in SGA infants

We found that among mothers with diabetes during pregnancy, the proportion of SGA infants who achieved catch-up growth at 6 and 12 months of age was significantly lower than that among those without diabetes (P<0.05). In cases where mothers had placental abnormalities (e.g., velamentous placenta, placenta previa, placental abruption), the proportion of SGA infants who achieved catch-up growth at 18 months of age was lower than that in those without placental abnormalities, with the difference approaching statistical significance (P=0.088). No statistically significant differences in the proportion of catch-up growth were found under other conditions (i.e., presence of hypertension, liver or kidney diseases, umbilical cord abnormalities during pregnancy, or twin pregnancy) (all P>0.05), as shown in Table 2.

Table 2 Associations between risk Factors and catch-up growth among SGA infants

Factors	CUG1		CUG2		CUG3		CUG4		CUG5		CUG6	
	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes	No
Hypertension disorders of												

pregnancy												
No	32	21	50	20	48	19	42	9	20	7	12	4
Yes	44	23	47	20	50	17	45	16	33	10	20	6
P	0.550		0.869		0.697		0.277		0.800		1.000	
Gestational diabetes mellitus												
No	51	27	72	22	68	21	61	12	36	9	24	5
Yes	25	17	25	18	30	15	26	13	17	8	8	5
P	0.525		**0.027**		0.230		**0.041**		0.262		0.238	
Liver and kidney diseases												
No	73	39	91	35	92	33	82	22	49	16	32	9
Yes	3	5	6	5	6	3	5	3	4	1	0	1
P	0.141		0.298		0.701		0.374		1.000		0.238	
Placental abnormalities												
No	67	36	83	32	85	32	76	22	51	14	32	10
Yes	9	8	14	8	13	4	11	3	2	3	0	0
P	0.337		0.420		0.783		1.000		0.088		-	
Umbilical cord abnormalities												
No	67	37	85	34	86	34	76	24	48	17	29	10
Yes	9	7	12	6	12	2	11	1	5	0	3	0
P	0.528		0.679		0.351		0.294		0.325		0.568	
Twin twins												
No	53	36	74	34	80	29	70	21	42	14	28	9
Yes	23	8	23	6	18	7	17	4	11	3	4	1
P	0.145		0.256		0.887		0.780		1.000		1.000	

*CUG 1-6 represented weight catch-up growth at 3，6，9，12，18 and 24 months，respectively. “Yes” represents the occurrence of catch-up growth and “No” represents the absence of catch-up growth.

3.2.5 Association between feeding modality and catch-up growth in preterm SGA infants

Table 3 presents the association between different feeding methods and catch-up growth in SGA infants. Because complementary feeding was introduced after 6 months of age, introducing numerous confounding factors and rendering the feeding patterns more complex, only the association between feeding methods and catch-up growth before 6 months of age was analyzed. After controlling for potential confounding factors, including preterm status, maternal gestational diabetes mellitus and hypertension-related complications, and placental and umbilical cord abnormalities, multivariate logistic regression analysis demonstrated that fortified breast milk

feeding was associated with successful catch-up growth in SGA infants (3 months: OR = 3.890, 95% CI: 1.103–13.721, P = 0.035; 6 months: OR = 10.432, 95% CI: 1.812–60.052, P = 0.009). Multiple imputation sensitivity analysis further verified that the strength of association and statistical significance of the core variables did not change substantially, confirming that the study findings were minimally affected by missing data and that the conclusions were robust and reliable.

Table 3 Relationship between catch-up growth and feeding patterns in SGA infants

Variables	Feeding patterns (Reference group: breastfeeding) in 3 months			Feeding patterns (Reference group: breastfeeding) in 6 months		
Multiple imputation	*P*	*aOR*	*95%CI*	*P*	*aOR*	*95%CI*
Formula milk	0.407	1.704	0.480-6.049	0.336	1.713	0.572-5.129
Mixed	0.580	1.354	0.460-3.985	0.286	1.781	0.617-5.145
Fortified breast milk	0.035	3.890	1.103-13.721	0.009	10.432	1.812-60.052
Preterm	0.020	0.371	0.160-0.856	0.874	1.082	0.403-2.906
Gestational hypertension	0.812	0.898	0.365-2.205	0.975	1.015	0.404-2.550
Gestational diabetes mellitus	0.716	1.199	0.443-3.243	0.189	1.845	0.738-4.612
Placental abnormalities	0.491	1.526	0.454-5.134	0.683	1.253	0.424-3.705
Umbilical cord abnormalities	0.890	0.920	0.281-3.015	0.904	1.083	0.296-3.959
infection	0.920	1.195	0.034-42.363	0.553	0.415	0.023-7.6
Complete case	*P*	*aOR*	*95%CI*	*P*	*aOR*	*95%CI*
Formula milk	0.332	1.871	0.527-6.647	0.339	1.727	0.563-5.303
Mixed	0.493	1.471	0.488-4.432	0.324	1.694	0.594-4.831
Fortified breast milk	0.022	4.210	1.234-14.368	0.004	31.777	2.939-343.571
Preterm	0.027	0.363	0.148-0.893	0.761	0.870	0.354-2.136
Gestational hypertension	0.949	1.030	0.422-2.510	0.883	1.072	0.423-2.714
Gestational diabetes mellitus	0.627	1.250	0.508-3.079	0.097	2.114	0.873-5.118
Placental abnormalities	0.560	1.424	0.434-4.674	0.651	1.284	0.435-3.796
Umbilical cord abnormalities	0.831	1.136	0.350-3.685	0.900	1.079	0.330-3.522
infection	0.706	1.874	0.072-48.773	0.429	0.250	0.008-7.780

aOR, adjusted odds ratio; CI, confidence intervals.

3.3 Follow-up of motor development indicators

Figure 4 illustrates the trends in Peabody Developmental Motor Scale scores (gross motor, fine motor, and total development quotient) in SGA infants at each follow-up month. All scores exhibited nonlinear trends over time. A linear mixed model (LMM) analysis was conducted, incorporating five covariates: gestational age, birth weight Z-score, sex, gestational diabetes

mellitus, and gestational hypertension, as shown in Table 4. After comparative assessment of nested linear and quadratic multivariate linear mixed models, the quadratic specification was identified as the optimal model for GMQ and TDQ. For both outcomes, the quadratic model exhibited smaller AIC and BIC values, and the LRT yielded $P < 0.05$, demonstrating that incorporating the squared centered age term significantly improved model fitting and adequately captured the U-shaped longitudinal developmental trajectory with distinct developmental nadirs at approximately 12 months of age, indicating that 12 months represents a critical follow-up time point for developmental quotients in SGA infants. After adjusting for covariates, the fine motor quotient (FMQ) showed no significant trend over follow-up time and remained relatively stable overall, suggesting that fine motor development in SGA infants is minimally influenced by postnatal time. In addition, sex (boys exhibited higher developmental quotients), birth weight Z-score (higher Z-scores were associated with higher developmental quotients), gestational hypertension (positively associated with GMQ), and gestational diabetes mellitus (negatively associated with FMQ and TDQ) were identified as significant factors influencing developmental quotients in SGA infants. These high-risk factors warrant close attention during clinical follow-up.

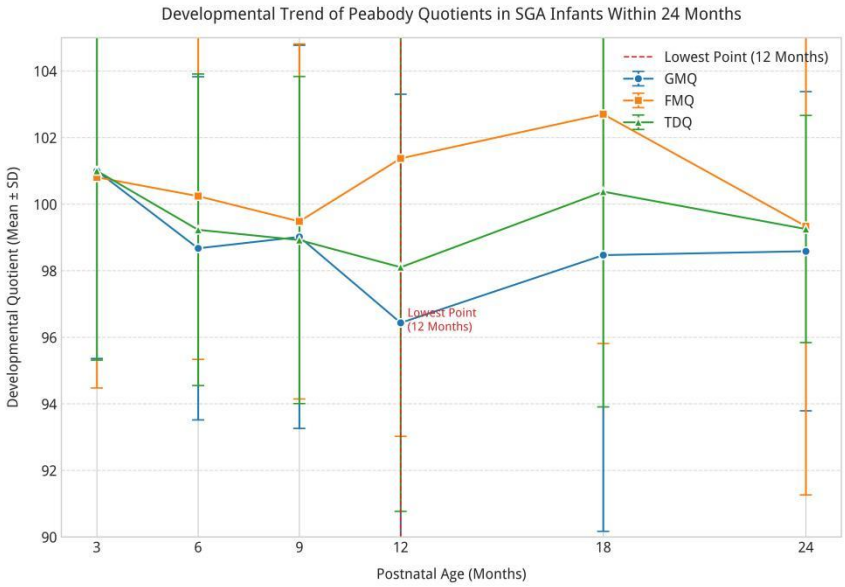


Figure 4 Developmental trend of Peabody Quotients in SGA infants within 24 months

Table 4 Multivariate quadratic linear mixed models for GMQ, FMQ and TDQ

Variables	GMQ		FMQ		TDQ	
	β (95%CI)	P-value	β (95%CI)	P-value	β (95%CI)	P-value
months_c	-0.291 (-0.44, 0.14)	<0.001*	0.072 (-0.10, 0.25)	0.421	-0.158 (-0.30, -0.02)	0.029*
months_c²	0.024 (0.008, 0.040)	0.004*	-0.000 (-0.02, 0.02)	0.997	0.019 (0.003, 0.035)	0.020*
Sex (Boy)	2.432 (0.73, 4.13)	0.005*	1.905 (0.35, 3.46)	0.016*	2.071 (0.51, 3.63)	0.009*
GA	0.275 (-0.02, 0.57)	0.069	0.146 (-0.13, 0.42)	0.293	0.208 (-0.05, 0.47)	0.118
BWZ	1.665 (0.10, 3.23)	0.037*	0.813 (-0.62, 2.25)	0.267	1.424 (0.00, 2.85)	0.05
HDP	1.958 (0.22, 3.70)	0.027*	0.774 (-0.81, 2.36)	0.337	1.126 (-0.41, 2.66)	0.151
GDM	-1.593 (-3.31, 0.12)	0.07	-2.268 (-3.82, -0.72)	0.004*	-1.969 (-3.53, -0.41)	0.014*

β：Coefficient of regression；SE：Standard error；c：Centered age；GA: Centered gestational age; BWZ: Centered birth weight Z; HDP: Hypertension disorders of pregnancy; GDM: Gestational diabetes mellitus;*: P<0.05

4 Discussion

This study described the longitudinal patterns of physical growth and motor development in SGA infants during the first two years of life. The main findings were as follows. First, most SGA infants achieved catch-up growth by 24 months of age, but the pattern of catch-up growth was uneven across anthropometric indicators. Head circumference showed relatively prominent catch-up, whereas early weight gain appeared faster than length gain. Preterm SGA infants exhibited more rapid catch-up in weight and length in the early period, whereas term SGA infants demonstrated more prominent long-term catch-up growth in head circumference. Second, maternal diabetes during pregnancy was associated with catch-up growth status. Third, fortified breast milk feeding at 3 and 6 months of age was associated with catch-up growth in SGA infants. Finally, gross motor quotient and total developmental quotient showed a nonlinear trajectory, with the lowest values observed around 12 months of age, suggesting that this may be a critical time point for motor-development surveillance, especially females and those born to GDM-complicated mothers.

SGA infants exhibit catch-up growth early after birth, with an incidence reaching 87.4%; 80% of SGA infants begin catch-up growth within the first 6 months after birth, and over 85% complete catch-up growth within 2 years [12]. SGA is caused by multiple factors, and maternal anthropometric indicators and metabolic abnormalities during pregnancy can affect neonatal birth weight and long-term catch-up growth. Studies have shown that pre-pregnancy underweight and obesity, as well as subclinical hypothyroidism during pregnancy, are associated with a higher risk of SGA and low birth weight [15–16]; meanwhile, SGA children born to mothers with pre-pregnancy underweight or inadequate gestational weight gain are at a higher risk of a "no catch-up growth" pattern [17]. Research has clearly identified associations between various pregnancy complications and catch-up growth outcomes in SGA infants. Among these, gestational hypertension, gestational diabetes mellitus, and preeclampsia are the most frequently studied exposure factors. For example, a study on term SGA infants found that gestational hypertension, gestational diabetes, and maternal overweight/obesity were negatively associated with weight catch-up growth in SGA infants [18]. The results of this study also demonstrate that SGA infants exhibit catch-up growth early after birth, with approximately 87.3% completing catch-up growth by 24 months of age, and that the proportion achieving catch-up growth at 6 and 12 months was significantly lower in those whose mothers had diabetes during pregnancy compared to those without diabetes. Therefore, preventive interventions during pregnancy can reduce the risk of SGA and also prevent the occurrence of a "no catch-up growth" pattern. Developmental screening should be strengthened for SGA infants with related risk factors.

Different types of SGA exhibit distinct catch-up patterns. This study showed that the physical indicators of SGA infants gradually approached those of the normal population. Similar studies have demonstrated that catch-up growth after birth in SGA infants cannot enable height, weight, head circumference, and other physical development indicators to catch up with those of AGA infants in a short period; however, over time, the gap gradually narrows, eventually reaching physical development levels similar to those of normal controls [19]. SGA infants exhibit significant heterogeneity in catch-up growth characteristics after birth. The fastest growth phase for term SGA infants is the first 3 months after birth, with faster catch-up rates for weight and head circumference than for length [20]. A study on the characteristics of catch-up growth in physical indicators within 3 years of age in very preterm SGA infants reported that the Z-scores of

all three physical indicators in the very preterm SGA group were negative within the corrected age of 12 months, and all turned positive after 12 months of age. Among these, the catch-up trends for weight and head circumference gradually slowed after corrected 12 months, while length continued to show a catch-up trend [21].

Brain structural defects are common in SGA children, leading to reduced head circumference [22]. The growth of head circumference in children is directly related to the development of the brain and skull. Head circumference in SGA children, particularly before 2 years of age, is of great significance for the early identification and intervention of neurobehavioral developmental delays [23]. Failure of catch-up growth in SGA children is an important cause of adverse cognitive outcomes [24]. One study found that approximately 15% of term SGA infants failed to achieve catch-up growth in height, and these children had a significantly increased risk of motor developmental delay at 2.5 years of age (OR 10.42; 95% CI 5.55–19.56) [25]. Moderate catch-up growth can improve neurobehavioral development and enhance cognitive abilities; however, excessive "weight catch-up" offers limited benefits for cognitive development [23] and instead significantly increases the risk of adverse outcomes such as insulin resistance and adult metabolic syndrome [26–28]. Studies specifically investigating motor development in SGA children using the PDMS/PDMS-2 as the primary assessment tool are scarce. One prospective randomized controlled trial found that an early intervention program guided by the Peabody Developmental Motor Scales-2 (PDMS-2) was superior to standard care for motor development in preterm infants with IVH [29]. At corrected 12 months, significant differences were observed between groups in both FMQ and GMQ ($p<0.001$), with large effect sizes ($\eta^2 > 0.21$), suggesting that PDMS-2 assessment is a method that can optimize early motor outcomes in this high-risk population at 12 months of age. This is consistent with our finding that 12 months is a critical time point requiring focused attention on motor development in SGA children.

Breast milk is the optimal nutritional source for infants, providing an appropriate ratio of protein and fat as well as natural immunoglobulins. Breastfeeding may positively influence growth programming due to the energy efficiency of its nutrients. One study analyzed the impact of early feeding modalities on later growth trajectories and found no significant differences in growth rate or catch-up growth between 6–12 months and 12–18 months of age [30]. Growth rate during the first 6 months, influenced by feeding modality, is a major predictor of early growth

trajectories. Late preterm SGA infants who were breastfed at discharge had a lower risk of failure to achieve catch-up growth in weight and length at 36 months of age[31]. However, some studies have shown that among children with catch-up growth, nutrient-enriched formula feeding promotes faster catch-up in length and weight and increases BMI compared with breastfeeding [32]. Nevertheless, the impact of high-protein, high-energy nutritional regimens on long-term neurological development remains controversial.

In recent years, the application of growth hormone therapy for short stature in SGA children has been widely studied [33–34]. Other studies on signaling pathways related to catch-up growth in SGA have shown that miR-576-5p is a predictor of weight and height catch-up at 1 year [35], and that cord blood miRNAs may serve as novel biomarkers for early identification of catch-up growth in SGA infants, potentially offering new therapeutic targets for future research.

This study has several limitations. First, children with higher health risks are more likely to undergo follow-up. The SGA infants followed up at our Child Health Development Center were mostly those who required close monitoring after NICU admission. More specifically, children with complete follow-up data tended to have more health conditions at birth, and their mothers may have had more pregnancy complications. Therefore, this may limit the generalizability of our findings. Second, some participants were lost to follow-up during the study. Although multiple imputation was used to handle missing data and sensitivity analyses were conducted, which to some extent controlled for the impact of data missing on the results, the potential interference of attrition bias still cannot be completely excluded. Third, despite the inclusion of various confounding factors in the adjusted models, there may still be unmeasured or incompletely quantified confounders that could influence the study findings. Finally，the data were derived from a single center, affecting the external validity of the results. Therefore, larger-sample, multicenter cohort studies are needed to confirm or refute our conclusions.

Conclusion

The physical growth trajectory and motor development of SGA infants have distinct characteristics. Fortified breast milk feeding was associated with catch-up growth. 12 months of age may be a critical time point for motor-development surveillance, especially females and those

born to GDM-complicated mothers. However, The underlying mechanisms require further investigation, and validation through multicenter, large-sample studies is needed.

Abbreviations

SGA

Small for gestational age

CUG

Catch-up growth

PDMS-2

Peabody Developmental Motor Scales, Second Edition

GMQ

Gross motor quotient

FMQ

Fine motor quotient

TDQ

Total developmental quotient

LMM

Linear mixed model

AIC

Akaike information criterion

BIC

Bayesian information criterion

LRT

Likelihood ratio test

Authors' contributions

The authors' responsibilities were as follows: KL, YX designed the trial; KL wrote the manuscript; YX analysed data, KH and ML designed table and figures; and ZG, XZ and ML participated in the drafting and editing of the manuscript. All authors read and approved the final

manuscript.

Ethics approval and consent to participate

This study was approved by the Medical Science Research Ethics Committee of Peking University Third Hospital (Ethics Approval No.: IRB00006761-M2024256). Participants were all children under 16 years of age, and informed consent for participation was obtained from their parents or legal guardians.

Availability of data and materials

Data supporting the findings of this study are available from the Center for Child Health and Development, Peking University Third Hospital, but there are restrictions on the availability of these data, which are used with ethically informed permission and are not publicly available because they involve personal data.

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Competing interests

There are no conflicts of interest.

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