ORIGINAL ARTICLE

Impact of Maternal Anthropometry and Infant Feeding on Growth Parameters of Infancy

Yumnah Babar[1*], Mubashra Tahir[2], Sundus Saba[3] and Maryem Sarwar[3]

[1]*School of Public Health, Nanjing Medical University, Nanjing, China*
[2]*Cantonment General Hospital, Rawalpindi, Pakistan*
[3]*Pakistan Atomic Energy Commission General Hospital, Islamabad, Pakistan*

Abstract

Background: Maternal and child health is a pressing issue, especially in developing countries like Pakistan, where mothers' health and feeding methods directly influence infant health and future outcomes.

Objective: The study investigates the impact of maternal prenatal anthropometry and gestational weight gain on infant birth indices, and the associations of different feeding methods with infants' anthropometric characteristics.

Methods: The study was conducted at the gynaecology department of the Pakistan Atomic Energy Commission General Hospital, where expectant mothers were enrolled throughout 2022, and demographic, prenatal, and infant data were collected. Correlation and regression analyses assessed the influence of prenatal anthropometry and gestational weight gain on birth anthropometry. Infants were stratified into Breastfed, Mixed-fed, and Formula-fed groups for longitudinal growth analysis across four time points using ANOVA, multivariate linear regression and growth trajectories.

Results: 366 mother-infant dyads were included in the analysis. Maternal pre-natal BMI, weight, height and gestational weight gain emerged as significant predictors of infant birth weight and length. Infants exclusively breastfed exhibited better growth indices and z-scores until six months than mixed or formula-fed. By the twelfth month, mixed feeding was associated with enhanced head circumference and HCZ scores. These growth findings were confounded by the birth weight of the infants and were higher for male infants than for female infants.

Conclusion: Maternal prenatal anthropometrics (weight, height, BMI) and gestational weight gain significantly influenced infant birth **size.** Notably, exclusive breastfeeding was associated with enhanced growth outcomes until six months of age compared to mixed or formula-fed infants.

Keywords: *Infant growth, gestational weight gain, maternal pre-pregnancy BMI, breastfeeding, mixed feeding, formula feeding.*

INTRODUCTION

The Developmental Origins of Health and Disease (DOHaD) theory highlights how maternal and infant factors during the first 1000 days of life (nutrition, BMI, stress, infections, feeding) critically shape long-term health trajectories and disease risk [1, 2]. In countries like Pakistan, where access to quality healthcare services is limited, the situation of maternal health is bleak due to factors such as inadequate prenatal care, malnutrition, and lack of access to skilled birth attendants, contributing to high rates of maternal and infant morbidity and mortality in the country [3]. Furthermore, infants born to already weak mothers face perinatal and neonatal complications, along with long-term adverse consequences on their health and growth [4]. Research has shown that maternal health is closely linked to infant health outcomes, with maternal malnutrition, infections, and other health issues increasing the risk of preterm birth, low birth weight, and neonatal mortality [5]. In Pakistan, where a large proportion of women face under-nutrition, contrarily, maternal obesity has emerged in urban cities of the country, posing a separate challenge to the health outcomes of pregnancy and their newborns [6-8].

Research has increasingly highlighted the importance of maternal pre-pregnancy body mass index (BMI) and gestational weight gain (GWG) as factors reflecting on maternal nutritional status, which has a direct impact on infants. Maternal obesity, characterised by a higher pre-pregnancy BMI, has been shown to correlate with higher infant birth weights and an increased risk of fetal overgrowth. Conversely, underweight mothers face an elevated risk of having small-for-gestational-age (SGA) infants [9-11]. Likewise, inadequate weight gain during pregnancy is associated with adverse outcomes, while excessive GWG is strongly linked to delivering macrosomic infants [12, 13]. These findings vary across different populations and need further delineation in terms of contributory factors.

The first postnatal year comprises crucial dietary transitions from exclusive milk feeding to solid foods, essential for adequate infant growth. According to WHO and UNICEF guidelines, exclusive breastfeeding is recommended for the first six months, followed by continued breastfeeding with nutritionally adequate complementary foods during weaning [14]. Despite

**Corresponding author: Yumnah Babar, School of Public Health, Nanjing Medical University, Nanjing, China, Email: yumnahb@njmu.edu.cn*
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these recommendations, global compliance with breastfeeding guidelines remains suboptimal. In Pakistan, the reported prevalence of mothers breastfeeding their children stands at 37.7% which is quite low [15].

While infant formulas strive to replicate the nutritional composition of breast milk, inherent differences in nutrient content and bioactive components can affect infant growth trajectories and long-term health outcomes. Studies indicate that formula-fed infants experience faster initial weight gain than their breastfed counterparts, which leads to variations in growth patterns, potentially resulting in increased risks of childhood obesity and metabolic disorders later in life [16-18]. Additionally, the practice of mixed feeding, where infants receive both breast milk and formula, is becoming more common, although the research exploring its effects on infant growth remains scant [19, 20]. Some research from various populations suggests potentially favourable growth in mixed-fed infants compared to those who are strictly formula-fed, while simultaneously acknowledging the potential benefits of exclusive breastfeeding for longer-term health [20-22].

Existing literature has largely emphasised the differences between exclusively breastfed and formula-fed infants or groups together mixed and formula-fed as 'non-exclusively breastfed', making it challenging to draw definitive conclusions about the impact of mixed feeding on growth outcomes.

This study aimed to investigate the relationship between maternal anthropometry and gestational weight gain on infant birth parameters in our population, and how various milk feeding methods affect growth trajectories throughout the first year of life. By examining these relationships, the research seeks to understand the impact of prenatal maternal factors and which feeding practices optimally support healthy growth during infancy to identify critical periods where one feeding method might be more beneficial than another.

METHODOLOGY

The current study was a prospective longitudinal study enrolling healthy pregnant women during 2022, who were expected to give birth during late 2022 to 2023. Verbal informed consent was obtained from all participating mothers (keeping in consideration the varying literacy rates and language understanding), and confidentiality and anonymity were ensured (no identification data, PRN numbers/name/addresses were kept for research). Ethical approval was granted by the relevant Institutional Ethical Committee, study protocol code PGHI-IRB (DME)-RCD-06-064. After birth, their infants were grouped based on feeding type (breastfed/formula-fed/mixed-fed) to examine associations with growth parameters till one year of life while accounting for maternal prenatal factors. Cochran's formula was used to estimate the required sample size based on the prevalence of breastfeeding among mothers in Pakistan (37.7%) derived from literature, keeping a confidence interval of 95% and a Margin of error 5% giving a sample size of 361. Considering the loss to follow up associated with longitudinal studies, 375 expecting mothers were enrolled by "convenience sampling" from the gynecology department at Pakistan Atomic Energy Commission General Hospital, Islamabad, Pakistan, throughout 2022, who gave birth to children during different times from late 2022 to 2023. The inclusion criteria were mothers aged <40, willing to breastfeed their infants, while for infants, the inclusion criteria were based on them being born alive and healthy and at full term (37-42 completed weeks of gestation). Any children born pre-term or with any congenital diseases, along with mothers who had any chronic disease preconception or developed any pregnancy-associated disease (gestational diabetes, pregnancy-induced hypertension, *etc*.) were excluded. Out of 375 mothers who consented, one had chronic hypertension, two were diagnosed with gestational diabetes, four had pre-term delivery, and two had infants born with congenital abnormalities and were hence excluded from the study. 366 mothers were finally enrolled in our current study, and data collection ensued.

After obtaining informed verbal consent from a total of 366 mothers, data regarding their pre-conception weight, height, demographic measures and education status were obtained using structured face-to-face interviews at their first antenatal visit. Data was refined to obtain the variables of interest: maternal preconception weight, height, and age. The mother's past medical history, antenatal and postnatal history were obtained from the maternal records and discharge summaries. At the time of the infant's birth, their mode of delivery, gestational age, birth weight in grams and length and head circumference in centimetres were obtained from the infants' medical records. Follow-up measurements of weight, length and head circumference were taken at first, fourth, sixth and twelfth months (one year) of age for all the infants enrolled in our study, coinciding with their vaccination schedules. The same standard instruments were used for all infants, and trained nursing staff were instructed to carefully note each measurement. Information regarding feeding during the past one month was obtained at each visit from the mothers using structured interviews at each of the follow-up visits, including details of what type of milk the infant received, primarily breast milk, formula and a combination of both. Breastfeeding was labelled as the BF group, where infants did not receive milk from any source other than breast milk. Mixed feeding classified in the MF group was defined where infants received both breast milk and formula, either as alternate feeds or in any proportion, as long as breastfeeding was still included in the milk sources with any type of formula. Finally, infants only receiving formula milk of any kind/ brand without any breast milk were put in the FF group.

The acquired data were refined for variables of interest. Maternal BMI was calculated using the standard formula, while the z scores for infant growth were calculated using the WHO anthropometry software v 3.2.2, including weight-for-age (WAZ), length-for-age (LAZ), head circumference-for-age (HCZ), and weight-for-length (WLZ) scores. Weight and length gain between each interval were also calculated. Three groups of milk feeding were identified from the obtained data as exclusively breast-fed (BF), mixed-fed (MF) and exclusively formula-fed (FF) according to the feed received in the past month by the infants at each visit. Multiple techniques in which Breast milk was fed directly or indirectly *via* a bottle were all categorised into the BF group. The infants who received breast milk and formula in any proportions/alternate feeds were grouped into the MF group. Infants not receiving any breast milk and only formula milk were placed in the FF group for analysis. Details of other supplements, foods and liquids, including water fed to the infants during twelve months, were not considered in this study.

Statistical Analysis was performed using SPSS (v.27). Descriptive statistics were computed for all continuous variables, and normal distribution was assessed using skewness, kurtosis, Q-Q plots and Shapiro-Wilk tests (p-value > 0.05) **(Appendix A)**. All variables were found to have a normal distribution. Pearson's correlation was computed, and multiple linear regression was conducted on maternal pre-pregnancy weight, height, BMI and gestational weight gain for infant birth weight and length while controlling for confounders of Maternal age, Infant gender, Mode of delivery and gestational age. One-way ANOVA and multivariate linear regression were applied to the variables of infant weight, weight gain, length, length gain, head circumference, WAZ, LAZ, HCZ, and WLZ scores at each visit from birth to twelve months based on the milk feeding groups while addressing confounders. A significance level of $P < 0.05$ was kept for all analyses. Growth trajectories for each milk feeding group (BF, MF, and FF) were plotted concerning infant age in months for growth indices of infant weight, weight gain, length, length gain, head circumference, and all z-score variables to obtain the trends of growth over time. The data was rechecked after analysis, and a reanalysis was carried out to ensure the reliability of the obtained results.

RESULTS

Demographics

The demographics of the initially enrolled mother-infant dyads are listed in Table **1**, and the values are presented as (mean ± standard deviation) unless listed otherwise. The study population consisted of full-term mother-infant dyads with balanced gender distribution. Most infants were delivered vaginally, with cesarean section accounting for slightly over one-third of deliveries. Mothers were generally young adults with normal pre-pregnancy body mass indices, reflecting a healthy study population at baseline. The cohort had normal regional anthropometrics, with maternal height, weight, and pregnancy weight gain within expected healthy ranges. Out of the initial 366 mothers, 359 (98%) completed the one-year follow-up.

Table 1: Participant characteristics (mother and infants).

Baseline characteristic	Value
Sample size (n)	366
Male infants (n)	196
Female infants (n)	170
Gestational age (weeks), mean±SD	39.6 ± 1.06
Vaginal delivery "n (%)"	230 (62.8%)
Caesarean section "n (%)"	136 (37.2%)
Maternal pre-pregnancy BMI (kg/m^2), mean±SD	21.79 ± 2.39
Maternal weight (kg), mean±SD	55.6 ± 6.3
Maternal height (cm), mean±SD	160.7 ± 4.5
Maternal age (years), mean±SD	27.2 ± 3.9
Gestational weight gain (kg), mean±SD	14.57 ± 5.50

Correlation Analysis on Prenatal Measures and Birth Indices

Pearson's correlation analysis revealed that maternal pre-pregnancy weight was positively correlated to infant birth weight ($r = 0.173$, $p < 0.001$), and height was positively correlated to infant birth length ($r = 0.204$, $p < 0.001$). Correlation of BMI with birth weight and length also revealed significant positive correlations with ($r = 0.230$, $p < 0.001$) for infant birth weight and ($r = 0.140$, $p = 0.007$) for birth length with maternal pre-pregnancy BMI. The respective scatter plots are presented in **Fig. (1)**. Gestational weight gain also significantly positively correlated to both infant birth weight ($r = 0.181$, $p < 0.001$)

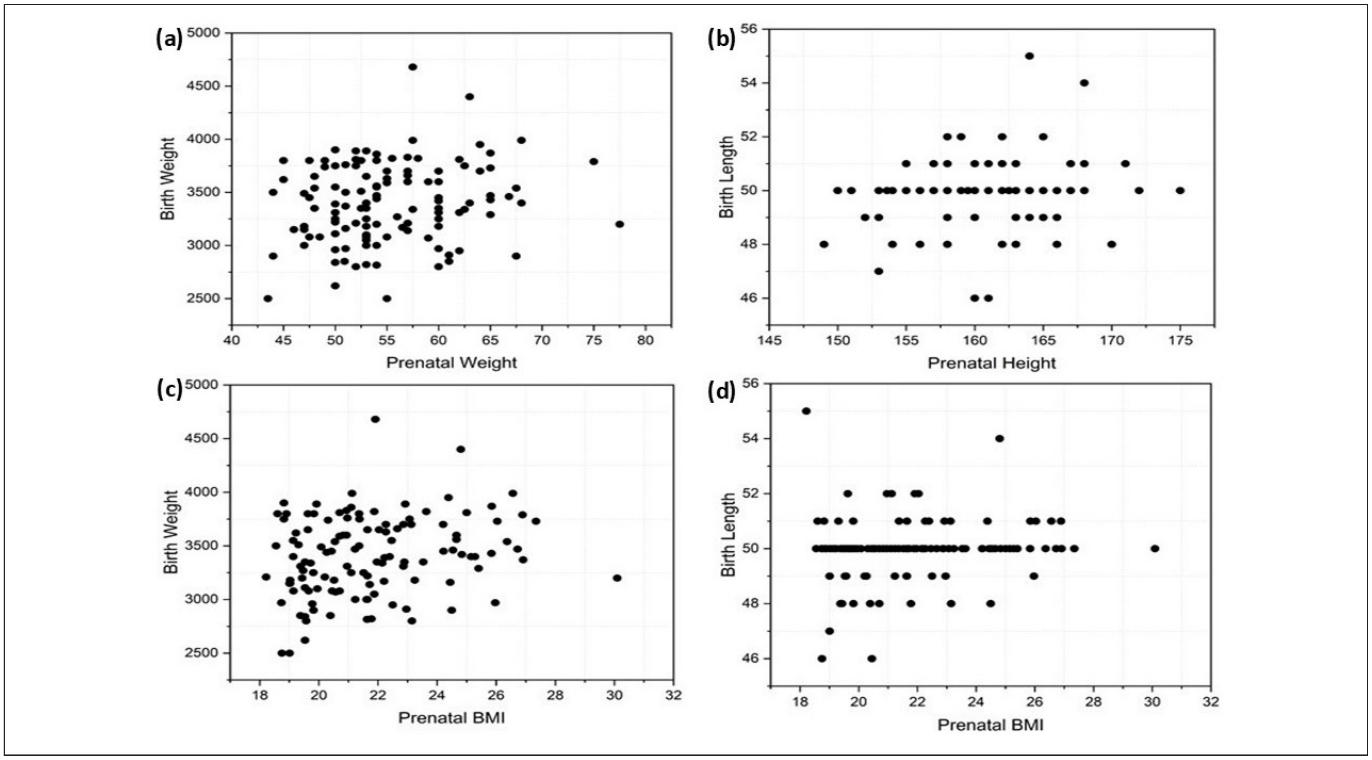

Fig. (1): Correlation scatter plots (**a**) Birth weight *vs.* Prenatal weight, (**b**) Birth length *vs.* Prenatal height, (**c**) Birth weight *vs.* Prenatal BMI and (**d**) Birth length *vs.* Prenatal BMI.

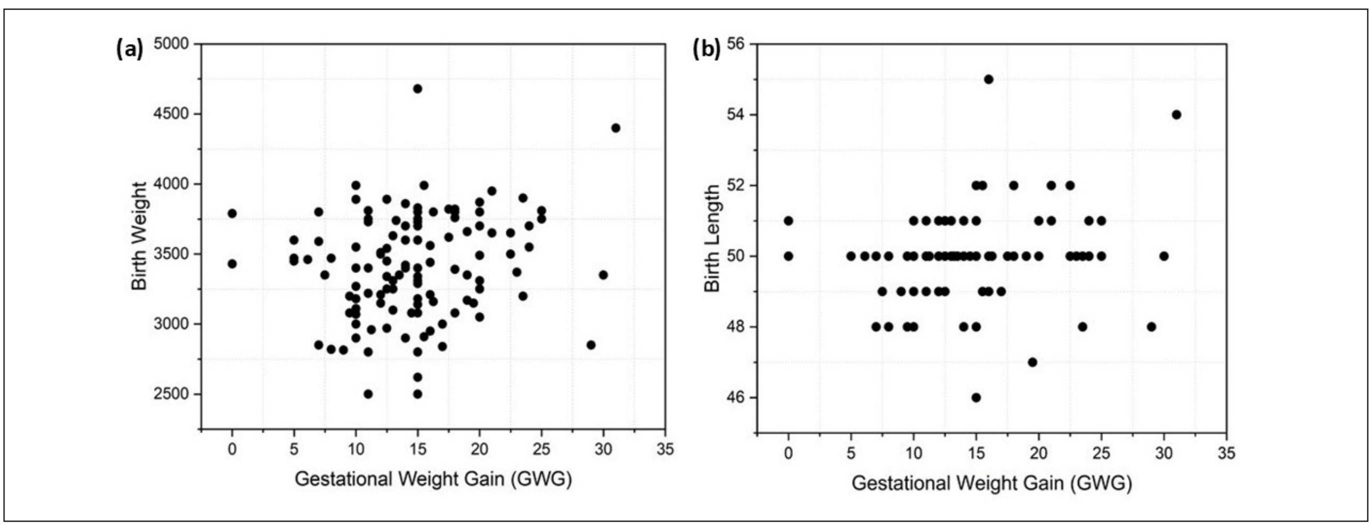

Fig. (2): Correlation scatter plots for (**a**) gestational weight gain and birth weight and (**b**) birth length.

and birth length (r = 0.171, p = 0.001), as presented in **Fig. (2**). These findings indicate that maternal weight, height, BMI and Gestational weight gain contribute to better birth weight and length in infants in our study population.

Multivariate Linear Regression Analysis on Prenatal Measures and Birth Indices

Multivariate linear regression was conducted between variables of infant birth weight and length with the respective prenatal measures, BMI and gestational weight gain after adjusting for confounding factors of infant gender, maternal age, mode of delivery and gestational age. The results indicated that the obtained outcomes were independent of the effect of confounders, with a significant impact of prenatal weight, height, BMI and Gestational weight gain on Infant birth weight and length (**Table 2**).

Breast-fed, Mixed-fed, and Formula-fed Infants' Growth

Nine growth parameters of Weight, Length, Head Circumference, WAZ, LAZ, HCZ, WLZ, Weight gain and Length gain were assessed among the three

Table 2: Multivariate linear regression between infant and maternal prenatal anthropometry with confounders.

Outcome	Predictor	β coefficient (95% CI)	p-value
Birth Weight	Prenatal Weight	2.91 (2.34-3.48)	0.004*
	Prenatal Height	0.338 (0.27-0.40)	<0.001*
	Prenatal BMI	0.481 (0.39-0.57)	<0.001*
	Gestational weight gain	0.193 (0.16-0.23)	<0.001*
	Maternal Age	0.018 (0.01-0.02)	0.720
	Gestational Age	-0.25 (-0.30, -0.20)	0.630
	Mode of delivery	-0.63 (-0.75, -0.51)	0.204
	Gender	0.005 (0.004-0.006)	0.919
Birth Length	Prenatal Weight	3.58 (2.88-4.28)	<0.001*
	Prenatal Height	0.406 (0.33-0.48)	<0.001*
	Prenatal BMI	0.438 (0.35-0.52)	<0.001*
	Gestational weight gain	0.173 (0.14-0.21)	<0.001*
	Maternal Age	0.46 (0.37-0.55)	0.373
	Gestational Age	-0.44 (-0.53, -0.35)	0.406
	Mode of delivery	-0.64 (-0.77, -0.51)	0.206
	Gender	0.008 (0.006-0.010)	0.882

*Note: *Significant at p-value ≤0.05.*

Table 3: Growth indices in the feeding groups on all visits assessed using ANOVA.

Age	Parameter	Breast-fed	Mixed-fed	Formula-fed	F-value	p-value
1 month	Weight (g)	5035 ± 550	4640 ± 537	4048 ± 549	38.81	*<0.001
	Length (cm)	56.3 ± 2.1	55.6 ± 2.3	54.1 ± 1.97	14.09	*<0.001
	Head Circ (cm)	37.8 ± 1.4	37.6 ± 1.3	36.8 ± 0.82	6.14	*0.002
	WAZ	0.85 ± 0.68	0.40 ± 0.81	-0.71 ± 0.95	40.82	*<0.001
	LAZ	0.81 ± 0.95	0.62 ± 0.88	-0.22 ± 0.97	12.97	*<0.001
	HCZ	0.53 ± 1.14	0.50 ± 1.07	-0.30 ± 0.77	7.03	*0.001
	WLZ	0.23 ± 1.01	-0.23 ± 0.98	-0.83 ± 1.17	13.23	*<0.001
	Weight gain (g)	1576 ± 455	1227 ± 416	918 ± 362	35.03	*<0.001
	Length gain (g)	6.07 ± 2.12	5.67 ± 1.70	4.91 ± 1.64	4.49	*0.012
4 months	Weight (g)	7724 ± 988	7269 ± 1009	7714 ± 855	7.69	*<0.001
	Head Circ (cm)	41.8 ± 1.5	40.9 ± 1.4	40.7 ± 1.6	2.96	*0.050
	WAZ	1.20 ± 0.87	0.61 ± 1.08	1.09 ± 1.05	8.77	*<0.001
	WLZ	0.89 ± 1.2	0.42 ± 1.13	0.88 ± 1.13	6.15	*0.002
	Length Gain (cm)	9.0 ± 1.7	8.5 ± 1.91	8.7 ± 1.72	3.02	*0.050
6 months	Weight (g)	8827 ± 1116	8350 ± 1034	8108 ± 523	11.60	*<0.001
	Length (cm)	68.7 ± 2.4	67.9 ± 2.2	68.0 ± 2.3	5.46	*0.005
	Head Circ (cm)	43.4 ± 1.3	42.8 ± 1.4	43.0 ± 1.5	9.59	*<0.001
	WAZ	1.32 ± 1.81	0.76 ± 1.03	0.62 ± 0.73	7.42	*<0.001
	HCZ	0.36 ± 1.06	0.05 ± 1.14	0.08 ± 1.1	3.58	*0.029
	WLZ	1.23 ± 2.13	0.65 ± 1.15	0.35 ± 1.13	6.61	0.002
12 months	Head Circ (cm)	45.9 ± 1.4	46.4 ± 1.3	45.7 ± 1.2	9.11	*<0.001
	HCZ	0.27 ± 1.1	0.57 ± 0.88	0.21 ± 0.87	5.05	*0.007
	Weight gain (g)	1440 ± 675	1452 ± 698	1675 ± 773	4.46	*0.012
	Length gain (cm)	7.3 ± 1.7	7.2 ± 2.1	7.9 ± 2.4	4.34	*0.014

*Note: Data is expressed as mean±SD, *Significant at p-value ≤0.05.*

feeding groups, and the measures that were found to be significant are shown in Table **3**. At one month, infants breastfed showed significantly higher mean weight, length, head circumference, WAZ scores, LAZ scores, HCZ, WLZ, weight gain and length gain than both mixed and formula-fed infants. At four months, breastfed infants still showed significantly higher weight, head circumference, WAZ score, WLZ and length gain than both mixed-fed and formula-fed infants. Between mixed and formula-fed infants, the latter had better growth indices than the former.

At six months, infants in the breastfed group had higher weight, length, head circumference, WAZ, HCZ and WLZ scores. The remaining growth indices had no significant difference among all three groups. Finally, at twelve months, mixed-fed infants had significantly higher head circumference and HCZ; formula-fed infants showed significantly higher weight gain and length gain, while the rest of the growth parameters were comparable among all three feeding groups.

These findings indicate that breast-fed infants exhibited higher growth rates until 6 months of age, while subsequent growth patterns were similar across feeding methods, except for mixed-fed infants, who showed better head circumference growth. In our study, formula feeding demonstrated a marginally better impact on overall growth compared to mixed feeding, suggesting it may be preferable to mixed feeding. However, it remains less favourable when compared to exclusive breastfeeding.

Multiple linear regression was applied to control for confounding variables (gender, birth weight, birth length, maternal age, mode of delivery and gestational weight gain). Through all four visits, birth weight and gender were implicated as significant confounders for most of the nine growth parameters, while the feeding group had a significant influence on almost all the growth measures. For the first visit, feeding had a significantly positive influence on all growth indices; by the second visit, the mixed-fed infants had a significantly negative impact on growth. For the third visit, the positive influence of breastfeeding remained only on weight, WAZ and WLZ scores. Upon the fourth visit at 1 year of age, mixed feeding showed a positive relationship with head circumference and HCZ scores, while a negative impact was seen on weight and length gains. The impact of formula feed was not significant for any of the parameters at any of the visits.

Growth Trajectories of Infants

Means of all the nine measured growth indices at one, four, six and twelve months for the BF, MF and FF groups were plotted over time as shown in **Fig. (3a-i)**. It was observed that the infants in the breast-fed group showed a higher increase in weight over time, but the lengths were comparable. The trajectory of head circumference

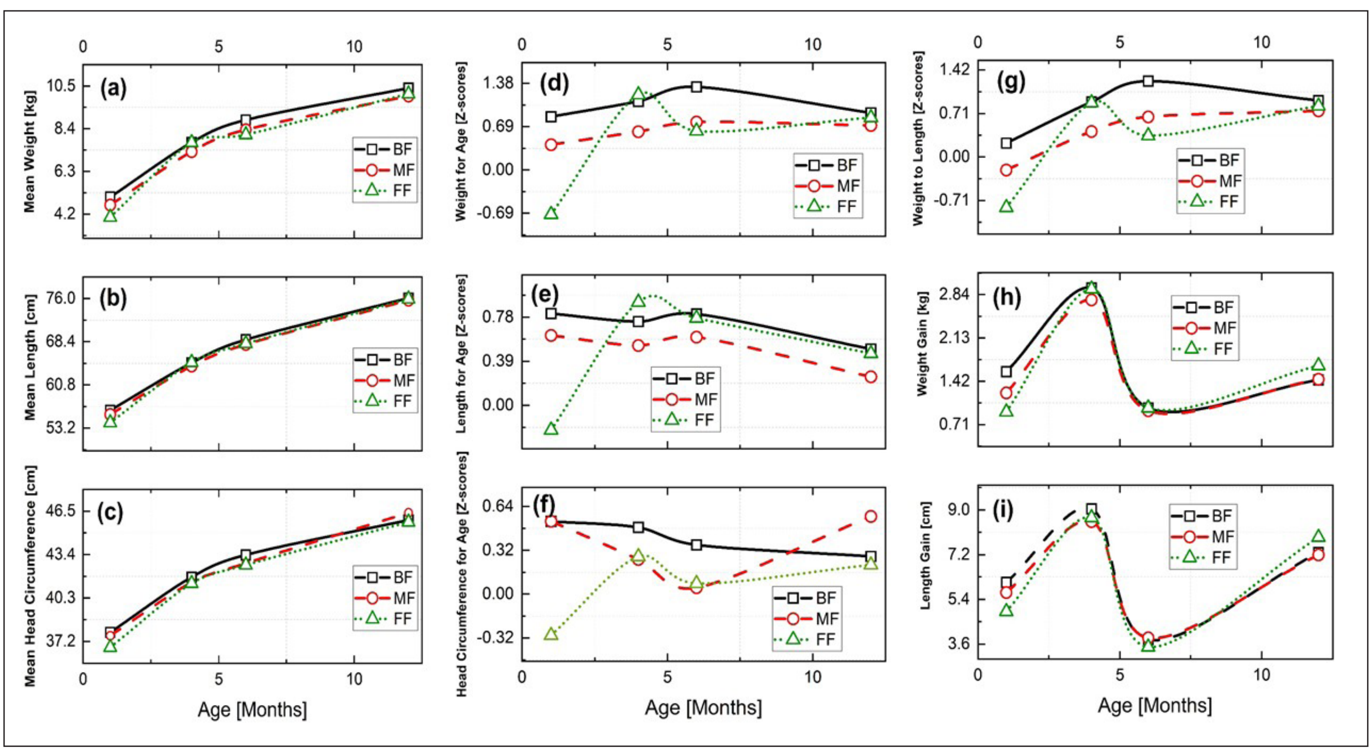

Fig. (3): Growth trajectories of all growth indices among the feeding groups during one year **(a)** Infant weight, **(b)** Infant length, **(c)** Infant head circumference, **(d)** WAZ scores, **(e)** LAZ scores, **(f)** HCZ scores, **(g)** WLZ scores, **(h)** Weight gain and **(i)** Length gain.

showed that mixed-fed infants eventually had a higher head circumference value by twelve months compared to the infants in the other two groups. The z-score plots showed an interesting pattern. WAZ and WLZ scores were higher for the BF group at every visit, while the MF group had consistently lower WAZ, LAZ and WLZ scores. The formula-fed infants had lower values of all the indices; however, they were slightly higher than those of the mixed-fed infants. The pronounced effect of better growth among breastfed infants was observed in weight, WAZ and WLZ scores, predominantly more so than other growth indices. The weight and length gains were also higher in the breast-fed group initially; however, by the end of the year, formula-fed infants took the lead.

DISCUSSION

In this study, we aimed to identify how maternal pre-pregnancy anthropometric characteristics and gestational weight gain influence infants' birth parameters, followed by the impact of milk feeding (exclusive breastfeeding, formula feeding and mixed feeding) on infants' anthropometry reflecting growth during the first year of life.

Maternal pre-pregnancy weight, height and BMI were found to be significant contributors to infants' birth weight and length, with no influence of covariates. These findings align with existing literature establishing gestational weight gain as a significant determinant of neonatal anthropometric outcomes [23, 24]. While previous studies have demonstrated correlations between maternal pre-pregnancy weight/height and neonatal birth parameters, most have focused specifically on maternal BMI's association with birth weight. Notably, maternal height's independent contribution to neonatal length has received limited investigation, potentially because paternal anthropometry - another established predictor of infant length [25, 26] often dominates such analyses. Our study, while not incorporating paternal measurements (a recognised limitation), provides new evidence for the direct relationship with birth length. These results reinforce the importance of preconception health counselling, particularly regarding achieving optimal BMI related to height, maintaining proper nutrition, and adhering to recommended gestational weight gain guidelines, all critical factors for promoting healthy fetal development.

Comparative analyses of growth patterns between breastfed and formula-fed infants have been extensively documented in the literature. The review of literature indicates that in developed countries, breastfed infants typically demonstrate lower weight gains and significantly reduced obesity rates compared to formula-fed infants after 3-4 months of age. While evidence suggests marginally slower linear growth during the first year among breastfed infants, these differences in height and weight typically resolve by 12 months [27]. Large-scale longitudinal studies have further demonstrated that breastfed children aged 6 months to 4 years maintain consistently lower weight and height percentiles than their formula-fed counterparts, with the most pronounced difference being significantly lower BMI values at 24 months [20]. Recent investigations incorporating mixed feeding modalities reveal important nuances: while no significant differences in thinness, overweight, or obesity prevalence were observed between mixed-fed and formula-fed infants, exclusively breastfed infants showed clear protection against both thinness and childhood obesity [28, 29]. Notably, accelerated weight gain among formula-fed infants, initially thought to reflect adiposity, has been shown to primarily represent increased lean mass accretion [25]. This body of evidence collectively supports the well-established protective role of breastfeeding against obesity.

Our findings contrast with most global studies but align with emerging evidence from Asian populations [30-32]. Breastfed infants in our cohort demonstrated superior growth indices compared to mixed- or formula-fed infants during early infancy (1 and 4 months). By six months, this advantage remained apparent only for weight-related measures. At twelve months, we observed an interesting shift: mixed-fed infants showed greater head circumference measurements, while other growth parameters became comparable across all feeding groups. These patterns suggest that feeding method effects on growth may be most pronounced in the first six months of life, with diminishing differences thereafter.

The observed growth patterns can be explained by several factors. Mixed-fed infants may show poor growth due to inconsistent nutrient intake from diluted formula or irregular breastfeeding, reduced nutrient absorption related to gut microbiome differences, and socioeconomic barriers such as limited lactation support. Formula feeding lacks breast milk's bioactive components, potentially disrupting metabolic programming. Additionally, mixed feeding is sometimes adopted when infants already have growth concerns, creating potential reverse causality. The confounding effect of birth weight further supports the lasting influence of maternal factors on growth, while male infants' different growth patterns likely reflect their higher bone density and distinct body composition compared to females. These findings reinforce the importance of exclusive breastfeeding for the first six months, followed by the timely introduction of nutritionally adequate complementary foods, with particular attention to both quality and quantity after six months to maintain optimal growth trajectories.

The observed growth patterns likely reflect both genetic factors and the advantageous socioeconomic conditions of our urban Pakistani cohort, where participants had consistent healthcare access and nutritional awareness. Mothers in our study maintained healthy pre-pregnancy BMIs and appropriate gestational weight gain, contributing to optimal infant birth weights. Breastfeeding further supported early growth through its unique nutritional components - benefits not equally achieved through mixed or formula feeding. However, our growth trajectory analysis reveals that these initial advantages gradually decrease after six months, coinciding with the introduction of complementary foods. At this stage, the nutritional quality of solid foods becomes the primary determinant of continued growth. These findings highlight the importance of supporting both exclusive breastfeeding for the first six months and providing nutrient-rich complementary foods thereafter to sustain infants' growth potential.

Several steps were taken to ensure the reliability and standardisation of study methodology. Growth indicators were obtained under strict quality control. The measuring tools were unified and calibrated before each use. All growth indicators for each visit were obtained at the same age in infants, and the error in the month of age did not exceed one week. The staff was trained and consistent for all visits to the infants. The loss of follow-up rate of our study was very low, and the absence of information from these mother-infant dyads did not significantly affect the overall impact on the results, maintaining the quality of the study.

LIMITATIONS

Limitations are acknowledged as sampling relied on convenience sampling and was conducted in a single hospital in one city in Pakistan. This limits the generalizability of the findings to mothers and infants from other areas of the country. Findings need to be validated in larger samples from multicenter studies. The study did not consider paternal anthropometry measures, particularly height, as a factor in infants' birth and growth indices, which could provide valuable information on infant length. While we present comparisons of growth indices across feeding groups, we acknowledge that not all analyses reached conventional levels of statistical power and analyses between groups were limited due to variations in sample sizes. No qualitative variables, including complementary food intake, were included in our analysis, a significant limitation which is likely to influence the growth trajectories observed in our study beyond six months. It is strongly recommended to be included in future research for a better understanding and replicability of the current findings.

CONCLUSION

The findings from our study indicate that Gestational weight gain, maternal pre-pregnancy BMI, weight and height are all important determinants of infant birth parameters; hence, women of reproductive age should be encouraged to maintain a healthy weight concerning their height, and gain adequate weight during pregnancy following the set standards to have infants with good birth weight and length. Infants exclusively breastfed had better growth indices, especially weight and weight gain, with corresponding z scores predominantly until six months of age, while mixed-fed infants had higher head circumference by twelve months of age as compared to those receiving formula feeding. Hence, compared to the practice of mixed and formula feeding, the practice of exclusive breastfeeding should be encouraged to get better absolute growth parameters for infants.

Interventions to encourage healthy pre-pregnancy BMI, gestational weight gain and improve exclusive breastfeeding (EBF) rates in Pakistan should include awareness campaigns and practical support for mothers (especially working), such as training on safe milk expression and storage techniques for convenient continuation of breastfeeding. Community health workers can play a key role in providing this guidance, while public awareness campaigns should promote expressed milk as a valid EBF option. Workplace policies and healthcare system support must also be strengthened to enable EBF continuity. Culturally tailored, multi-level strategies like these can help overcome barriers and ensure better infant feeding practices.

ETHICAL APPROVAL

Ethical approval was obtained from the Institutional Ethical Committee of PGHI, Pakistan Atomic Energy Commission General Hospital, H-11/4, Islamabad (REF letter No. PGHI-IRB (DME)-RCD-06-064, Dated: 5th March, 2025). All procedures performed in studies involving human participants were following the ethical standards of the institutional and/ or national research committee and the Helsinki Declaration.

CONSENT FOR PUBLICATION

Verbal informed consent was taken from the participants.

AVAILABILITY OF DATA

The data set may be acquired from the corresponding author upon a reasonable request.

FUNDING

None.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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AUTHORS' CONTRIBUTION

Yumnah Babar: Conceptualisation, Data Analysis, Validation, Formal analysis, Data curation, Writing Original Draft, Writing Reviewing and Editing, Visualisation.

Mubashra Tahir: Data Collection, Interviewing the study participants, Ensuring data accuracy and reliability.

Maryem Sarwar: Writing, Reviewing, and Editing, Data Storage, Data Curation

Sundas Saba: Ethical approval, Data Storage, Proofreading.

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Appendix A: Test of normality (Shapiro-Wilk).

Variables	Test Statistic (W)	p-value	Inference
Maternal factors			
Maternal Age	0.998	0.957	Normal (p >> 0.05)
Maternal Weight	0.981	0.112	Normal (p > 0.05)
Maternal Height	0.993	0.678	Normal (p >> 0.05)
Maternal BMI	0.985	0.245	Normal (p > 0.05)
Gestational Weight Gain	0.991	0.512	Normal (p >> 0.05)
Infant factors			
Birth weight	0.998	0.957	Normal (p >> 0.05)
Birth length	0.981	*0.112*	Normal (p > 0.05)
One month			
Weight	0.998	0.957	Normal (p >> 0.05)
Length	0.981	0.112	Normal (p > 0.05)
Head-circumference	0.993	0.678	Normal (p >> 0.05)
WAZ	0.985	0.245	Normal (p > 0.05)
LAZ	0.991	0.512	Normal (p >> 0.05)
HCZ	0.980	0.038	Borderline (0.01 < p < 0.05)
WLZ	0.997	0.891	Normal (p >> 0.05)
Weight Gain	0.987	0.324	Normal (p > 0.05)
Length Gain	0.983	0.187	Normal (p > 0.05)
Four months			
Weight	0.998	0.957	Normal (p >> 0.05)
Length	0.981	0.112	Normal (p > 0.05)
Head-circumference	0.993	0.678	Normal (p >> 0.05)
WAZ	0.985	0.245	Normal (p > 0.05)
LAZ	0.991	0.512	Normal (p >> 0.05)
HCZ	0.980	0.038	Borderline (0.01 < p < 0.05)
WLZ	0.997	0.891	Normal (p >> 0.05)
Weight Gain	0.987	0.324	Normal (p > 0.05)
Length Gain	0.983	0.187	Normal (p > 0.05)
Six months			
Weight	0.998	0.957	Normal (p >> 0.05)
Length	0.998	0.957	Normal (p >> 0.05)
Head-circumference	0.981	0.112	Normal (p > 0.05)
WAZ	0.993	0.678	Normal (p >> 0.05)
LAZ	0.985	0.245	Normal (p > 0.05)
HCZ	0.991	0.512	Normal (p >> 0.05)
WLZ	0.980	0.038	Borderline (0.01 < p < 0.05)
Weight Gain	0.997	0.891	Normal (p >> 0.05)
Length Gain	0.987	0.324	Normal (p > 0.05)
Twelve months			
Weight	0.998	0.957	Normal (p >> 0.05)
Length	0.981	0.112	Normal (p > 0.05)
Head-circumference	0.993	0.678	Normal (p >> 0.05)
WAZ	0.985	0.245	Normal (p > 0.05)
LAZ	0.991	0.512	Normal (p >> 0.05)
HCZ	0.980	0.038	Borderline (0.01 < p < 0.05)
WLZ	0.997	0.891	Normal (p >> 0.05)
Weight Gain	0.987	0.324	Normal (p > 0.05)
Length Gain	0.983	0.187	Normal (p > 0.05)