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Statistical Modeling for Analyzing Growth Using Weight and Height of Thai Children Aged 0-8.5 Years in the Prospective Cohort Study in the South of Thailand

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ABSTRACT

This study aimed to investigate the patterns of children's growth and to fit an appropriate statistical model for children's growth in South of Thailand. The study included 1,061 children from at birth in the prospective cohort study conducted in Thepa district in Songkhla province, Thailand. Linear regression model by taking reciprocal weight gain was used to analyze the weight gain at the first year of life base on feeding types at aged 21 days, 3 months, 6 months and 12 months as breast, mixed and bottle feeding. Feeding type was significant associated with weight gain in the first years of life. Weight gain in both boys and girls fed with formula feeding at age 21 days, 6 and 12 months were significantly higher than weight gain in breast milk and mixed method. Weight gain fed with mixed methods at aged 3 months was significantly higher weight gain of breast milk and formula feeding for both boys and girls. There was statistical association between type of feeding for one year with weight and height gain at aged 1, 3, 5 and 8.5 years. The height gain of boys at aged 1, 3 and 5 years and girls at aged 3.5, and 8.5 years fed by breast milk for one year were significantly lower than height gain by breast feeding and mixed methods. Infant feeding type is significant factor for determining weight gain at first year of life. Implementation the knowledge of nutrition in infant feeding methods for mothers should be emphasized.

Keywords: Weight, Height, Linear regression, feeding

INTRODUCTION

A child's growth is an important indicator for monitoring population nutritional status and healthiness. [1,2]. The insufficient nutrition during the first few years of life delayed the child's growth [3]. As malnutrition affects physical growth, there may be a substantial gap between children growth rates in developed and developing countries. In developed countries, the overweight is a major problem and the malnutrition is rare [4]. Malnutrition or underweight as a major public health problem among children in developing countries can affect physical and intellectual growth and is also considered as a main cause of child morbidity and mortality five years of age, accounts for at least half of all childhood death worldwide [5,6]. It is also recognized as the underlying cause of related deaths of childhood disease such as measles, diarrhea, and acute respiratory infectious diseases [5,6]. The main consequences of malnutrition have been explained as growth failure, impaired intellectual and physical development, lower resistances to infection and high incidence rate of some chronic disease [5]. Moreover, it affects human performance and decreases the population survival and enhance the economic burden [7,8]

Malnutrition and stunting in children is currently a serious public health concern in many countries. Children with a weight-for-height ratio more than three standard deviations (SD) below the mean based on WHO standards, had higher risk of death than children with weight-for-height above SD below the mean. The situation of the nutrition of Thai children in the period of the Eleventh National Economic and Social Development plan 2007-2011 found that in 2009, 4% of children aged 0-72 months in the South and 4.3% in the North of Thailand were underweight [9]. Thus, the aims of this study were to investigate the patterns of growth for children aged 0-8.5 years in the South of Thailand and to fit an appropriate statistical model for analyzing child growth from weight and height of Thai children aged 0-8.5 years in the prospective cohort study in the South of Thailand.

MATERIALS AND METHODS

Data sources

Children' growth records from a cohort of 1,061 children from the Thepa district in the Songkla province of Southern Thailand was obtained from The Prospective Cohort Study of Thai Children (PCTC). These data provide information on age, gender, infant feeding type at duration period, and weight and height of the infants. The PCTC in Thepa district is an observational community-based study designed to follow birth cohorts from about the 28th to 38th gestational week onwards, which was performed by physicians and specially trained research assistants. The children were followed up since their birth in 2001 to 8.5 years in 2011. Their weights and heights were measured at birth and at ages 1, 3, 5 and 8.5 years, respectively. The feeding types of children at aged 21 days, 3, 6 s and 12 months were taken noted by mothers or caregivers.

The outcomes of interest in this study were the weight and height gain at aged 1, 3, 5 and 8.5 years of the children in the PCTC study. These outcomes were used to compare the growth pattern of children who were given different types of feeding methods. The determinants in this study are feeding methods at aged 21days, 3, 6 and 12 months. Infant feeding methods are divided in to 3 groups: breast-feed, formula-feed and mixed-feed.

Statistical analysis

Linear regression model

Linear models were used to compare the weight gain and height gain of the children who were fed differently. Since weight gain and height gain are continuous outcomes and the determinant is feeding types at 21 days, 3, 6 and 12 months, the linear regression model was fitted. The model takes the form

$$y_i = \mu + \alpha_i \quad (1)$$

Where y_i is weight or height gain, μ is the overall effect, α_i is the effects of infant feeding types. Since the assumption of linearity of the linear model was not met, weight gain was transformed by taking reciprocal weight gain as the following form.

$$y_i = \frac{1}{wt_i} \quad (2)$$

The model was applied for boys and girls with feeding duration at 21 days, 3, and 12 months separately. Confidence interval obtained by using sum contrast to comparing means within each factors with the overall mean. An advantage of these confidence intervals is that they provide a simple criterion for classifying level of the factor into three groups according to whether each corresponding confidence intervals exceeds, crosses, or is below the overall mean. Coefficients from linear regression model were substituted in the equation (1) and converted back to be the weight gain or height. The 95% confidence intervals of weight gain or height were also calculated. Then all of these values were used to create the 95% CI plot. All statistical modeling and graphical displays were performed using R statistical software.

RESULTS

This study included 1,061 children from Thepa district in Songkhla province of Thailand. Table 1 shows the mean and SD of weight and length/height at age 0-8.5 years.

Table 1: Mean and SD of weight and length/height at age 0-8.5 years

Variables	Boys (mean±SD)	Girls (mean±SD)	P-value
Weight (kilograms)			
Below 1 year	3.1 ±0.5	2.9± 0.5	<0.001
1 year	8.9 ±1.1	8.4±1.1	<0.001
3 years	12.8±1.8	12.6±2.1	0.058
5 years	16.1±2.7	15.9±2.8	0.564
8.5 years	23.5±5.4	23.9±5.6	0.192
Height (centimeters)			
Below 1 year	49.8±2.5	49.34±2.6	<0.001
1 year	73.6±2.8	72.18±2.7	<0.001
3 years	91.2±3.8	90.25±3.6	<0.001
5 years	104.1±4.4	103.65±4.3	0.091
8.5 years	123.4± 5.5	123.47±5.7	0.788

The distribution of feeding type for boys and girls are shown in Table 2. At aged 21 days, boys were fed by breast milk 52.3% and mixed methods 43.9% whereas girls were fed by breast milk 57.1% and mixed methods 38.8%. At aged 3 months, 42.7% of boys and 50.1% of girls were fed by breast milk. At aged 6 months, 48% of boys and 50.7% girls were fed by breast milk. Lastly, 42.1% of boys and 50.7% of girls were fed by breast milk at aged 12 months.

Table 2: Distribution of feeding methods at four duration times by gender

Variables	Boys (n=548) Number (%)	Girl (n=513) Number (%)	P-value
Breast feeding at 21 days			0.333
Breast feeding	287(52.37)	293(57.12)	
Mixed feeding	241(43.98)	199(38.79)	
Formula feeding	18(3.28)	20(3.90)	
Unknown	2(0.36)	1(0.19)	
Breast feeding at 3 months			<0.001
Breast feeding	234(42.70)	257(50.10)	
Mixed feeding	236(43.07)	188(36.65)	
Formula feeding	75(13.69)	65(12.67)	
Unknown	3(0.55)	3(0.58)	
Breast feeding at 6 months			<0.001
Breast feeding	263(47.99)	260(50.68)	
Mixed feeding	164(29.93)	138(26.90)	
Formula feeding	118(21.53)	109(21.25)	
Unknown	3(0.55)	6(1.17)	
Breast feeding at 12 months			<0.001
Breast feeding	231(42.15)	237(46.20)	
Mixed feeding	151(27.38)	132(25.73)	
Formula feeding	161(29.38)	140(27.29)	
Unknown	5(0.91)	4(0.78)	

Weight and Height for age growth patterns of boys and girls for each feeding type

Figure 1 is a line plot showing the weight and height for age pattern of boys and girls. The grey lines indicate the weight and height for age pattern of the boys and girls while the average weight-for-age of boys fed with either breast, formula or mixed (i.e. both) are shown by the black, green and red lines, respectively. The top left graph shows the weight-for-age pattern of boys. The most rapid increase in weight-for-age occurred during the first year of life followed by a more steady increase. The lowest average weight-for-age occurred for boys were fed by breast feeding whereas the highest average weight-for-age for boys were fed by formula feeding. After the first year of life, the weight-for-age of boys who fed with formula feeding more increased rapidly than other two groups. The highest mean weight-for-age gain at each measurement time occurred for the boys who were fed by formula feeding in infancy. The top right graph shows that the height-for-age pattern for boys steadily increased regardless of the type of feeding. Again, the mean height-for- age gain of boys fed by breast, formula and mixed feeding are shown in black, green and red lines, respectively. The most rapid increased in height-for- age gain occurred in the first year. In the first year, the mean height-for-age gain of all boys were the same, however, boys fed by formula had slightly height-for-age gain than other groups and this increase was greatest between the first and third years of life. The increase in height-for- age gain tended to be the same for boys from each feeding type after the ages of four years. After the age of one year, boys fed by formula had the greatest average height-for-age gain on average, followed by mixed feeding and formula feeding had the lowest average height-for-age gain.

The bottom left graph shows a similar pattern in weight-for-age gain for of girl separated by type of feeding as for boys. The average weight-for-age gain of breast, formula and mixed feeding are again shown in black, green and red lines, respectively. The most rapid increase in weight-for-age occurred in the first year. Girls fed by formula feeding had the highest average weight-for-age gain whereas the lowest average weight-for-age gain was from girls fed by breast feeding. The increase in average weight-for-age gain appears less rapid increased after 3 years for girls who fed by breast feeding compare to the other feeding types. The bottom right figure shows that the height-for-age pattern for girls steadily increased regardless of the type of feeding. Again, the mean height-for- age gain of girls fed by breast, formula and mixed feeding are shown in black, green and red lines, respectively. The most rapid increased in height-for-age gain occurred in the first year. In the first year, the mean height-for-age gain of all girls were the same, however, girls fed by formula had slightly height-for-age gain than other groups and this increase was greatest between the first and third years of life. The increase in height-for-age gain of girls tended to be the same in all feeding type after the ages of four years. After the aged 1 year, girls were fed by formula had the greatest average height-for-age gain, followed by mixed feeding and the lowest average height-for-age gain was breast feeding.

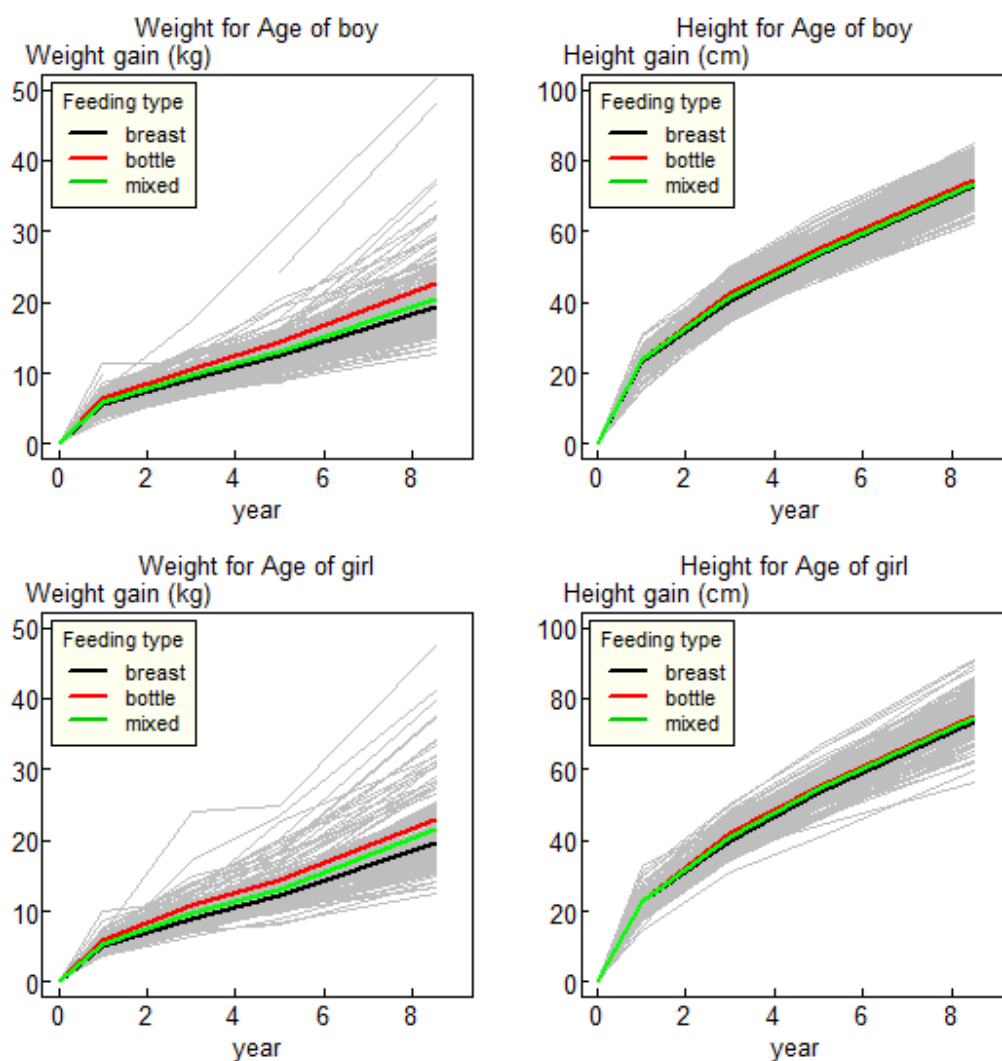


Figure 1: Line plot for weight for age of boy (top left), height for age of boy (top right), weight for age of girl (bottom left) and height for age of girl (bottom right) for each feeding type (breast, bottle and mixed).

Weight gains of boy and girl in the first year of life

The residual plots of weight gain at 1 year of boy and girl with infant feeding duration at age 21 days, 3, 6, and 12 month from linear regression model by taking reciprocal weight gain were showed in the figure below.

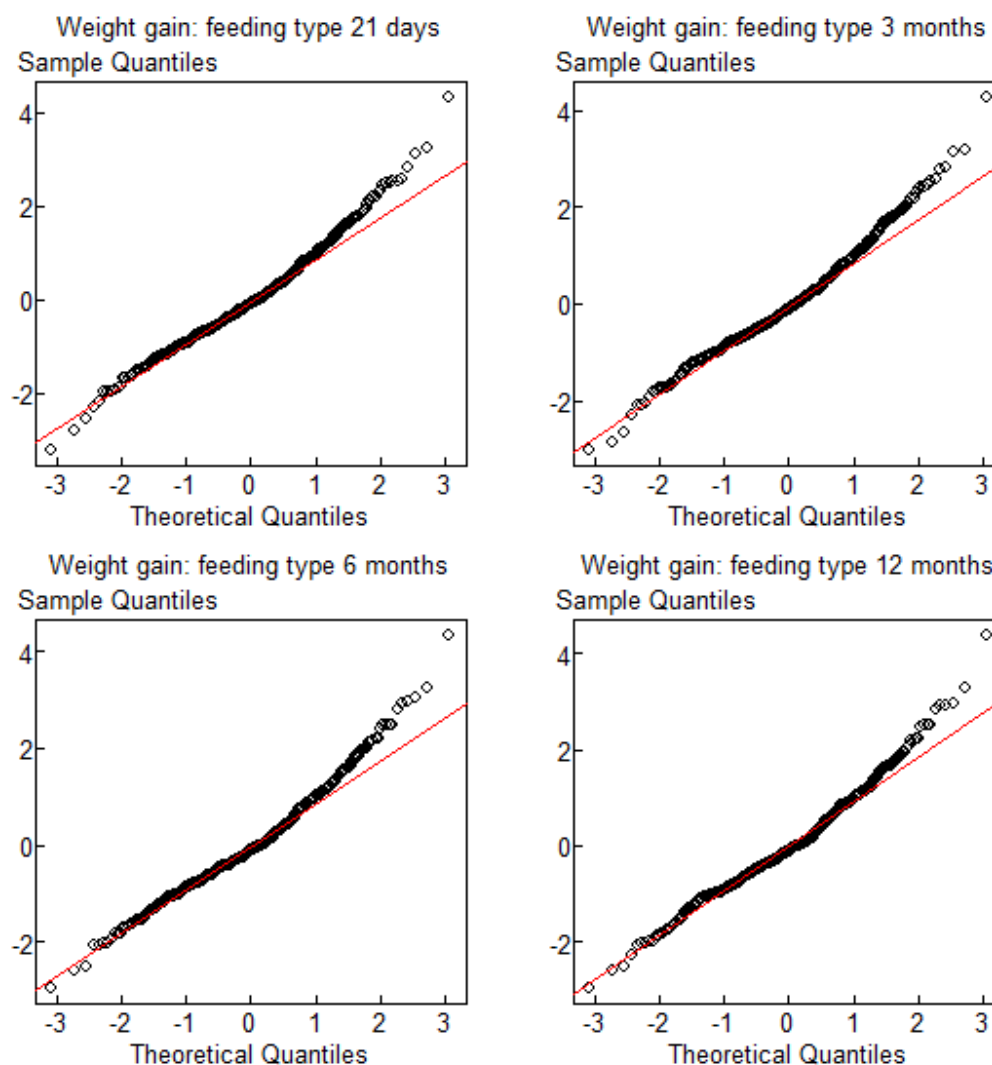


Figure 2: Residual plots from four weight gain models at age 1 year for boys on infant feeding type durations

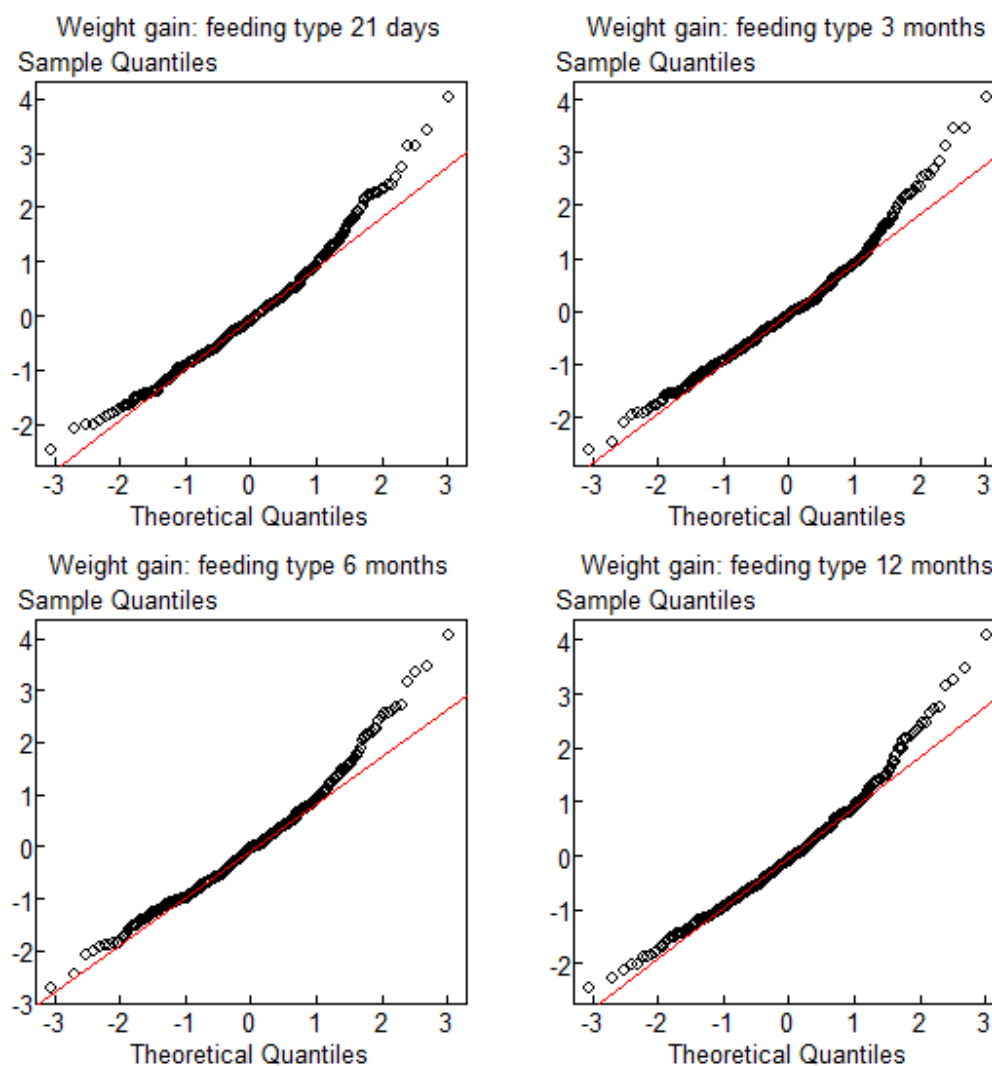


Figure 3: Residual plots from four weight gain models at age 1 year for girls on infant feeding type durations

Figures 2 and 3 show plots of residuals versus normal quartiles. Linear regression model of the reciprocal weight gain is an appropriate transformation method for modeling weight gain over the first year of life for both gender on infant feeding type durations. This model had acceptable fit with the data.

Figure 4 and 5 show the graph of the 95% confidence intervals of average weight gain over the first year of life of boy and girl for each feeding type (breast, mix or formula feeding) recorded at four different times (21 days, 3, 6, 12 months) estimated by simple linear model. The red horizontal line in each graph represents the overall mean weight gain of both boys and girls over the first year of life. The results show that infant feeding type at aged 21 days, 3, 6, and 12 months were statistically significant associated with weight gain over the first year of life. Weight gain of boys and girls fed with breast milk at age 21 days, 3, 6 and 12 months were statistically significant lower than overall mean. Weight gain of both boys and girls fed with mixed methods at aged 6 and 12 months were statistically significant higher than overall mean. Weight gain for both boys and girls fed with formula milk at aged 3 months were statistically significant higher than overall mean.

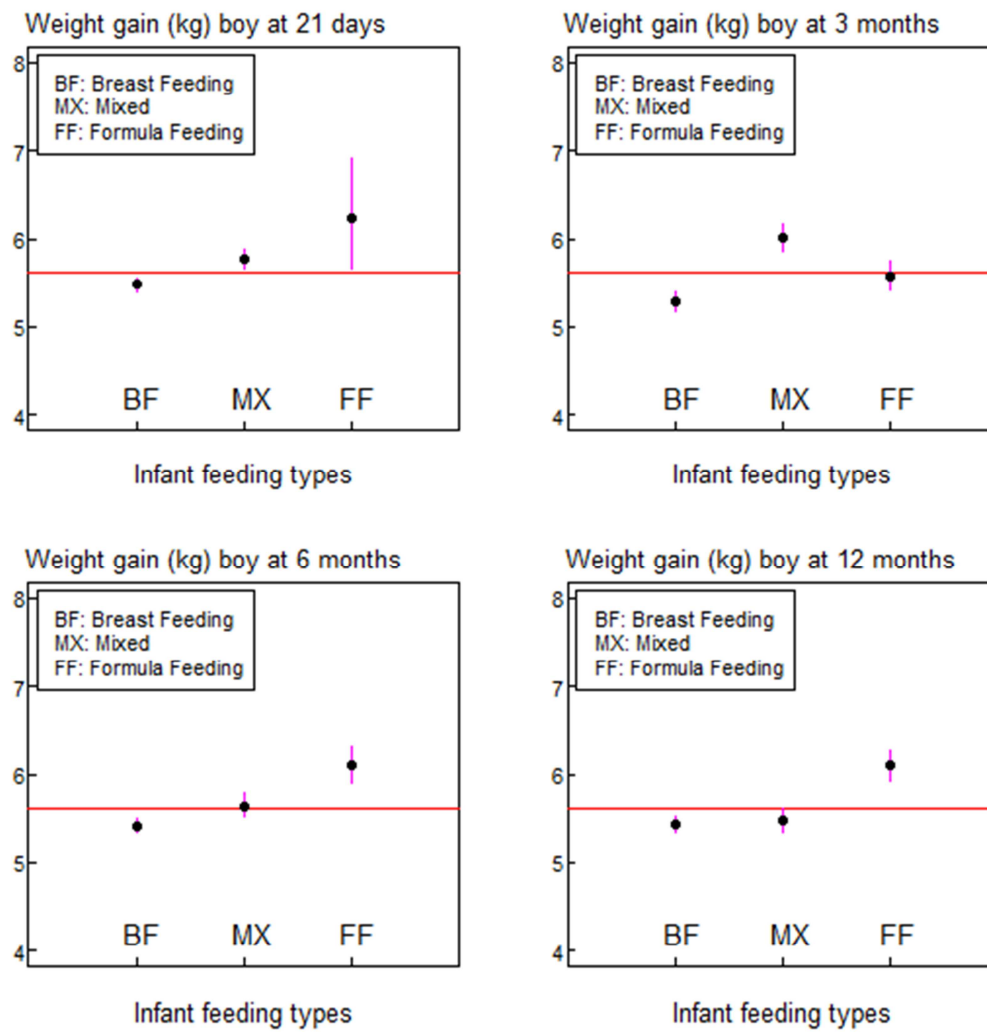


Figure 4: Plots of means and 95% confidence intervals of mean weight gains of boys by type of feeding of the infant at four different time periods.

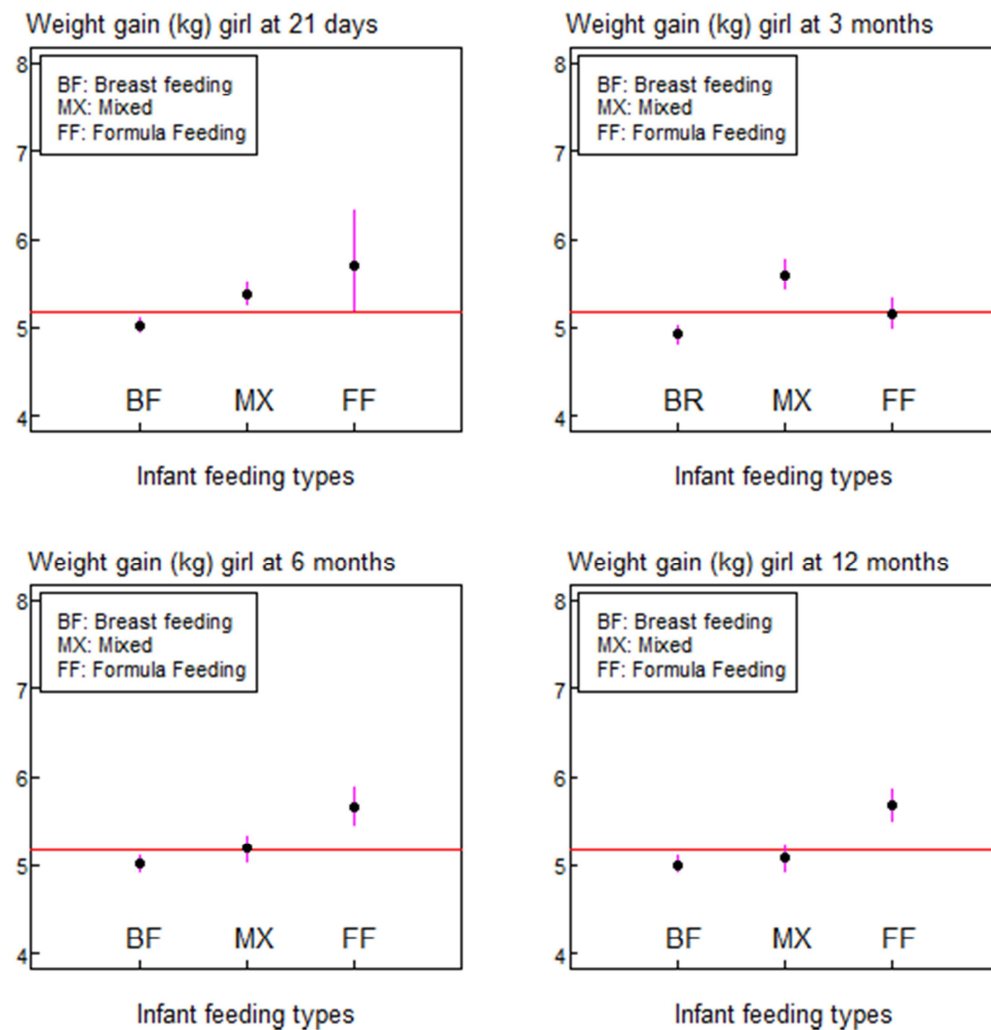


Figure 5: Plots of means and 95% confidence intervals of mean weight gain of girls by type of feeding of the infant at four different time periods.

Height gain of boys and girls in the first year of life

Figure 6 shows the residual plots of height gain at 1 year of boys and girls with infant feeding duration at age 21 days 3, 6, and 12 months from linear regression model .

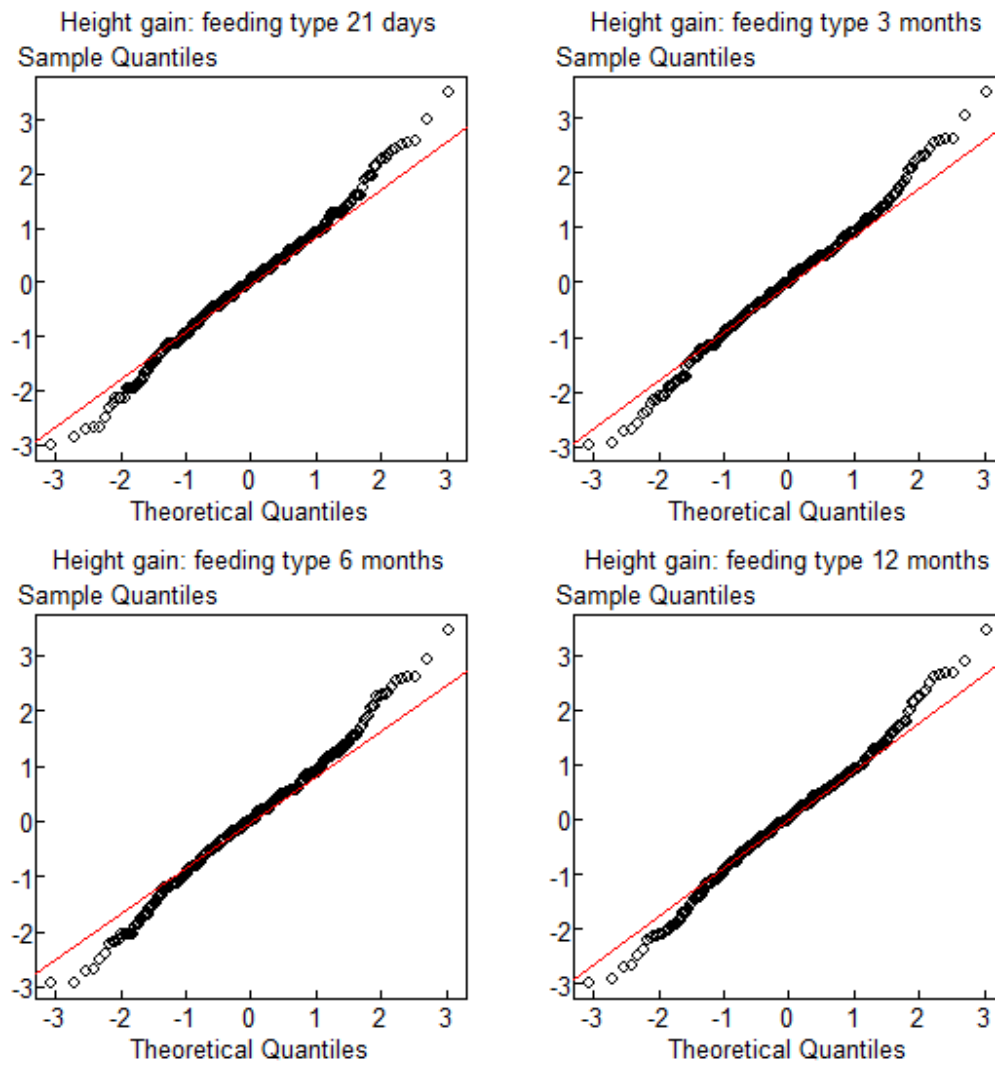


Figure 6: Residual plots from four height gain models at age 1 year for boys on infant feeding type durations

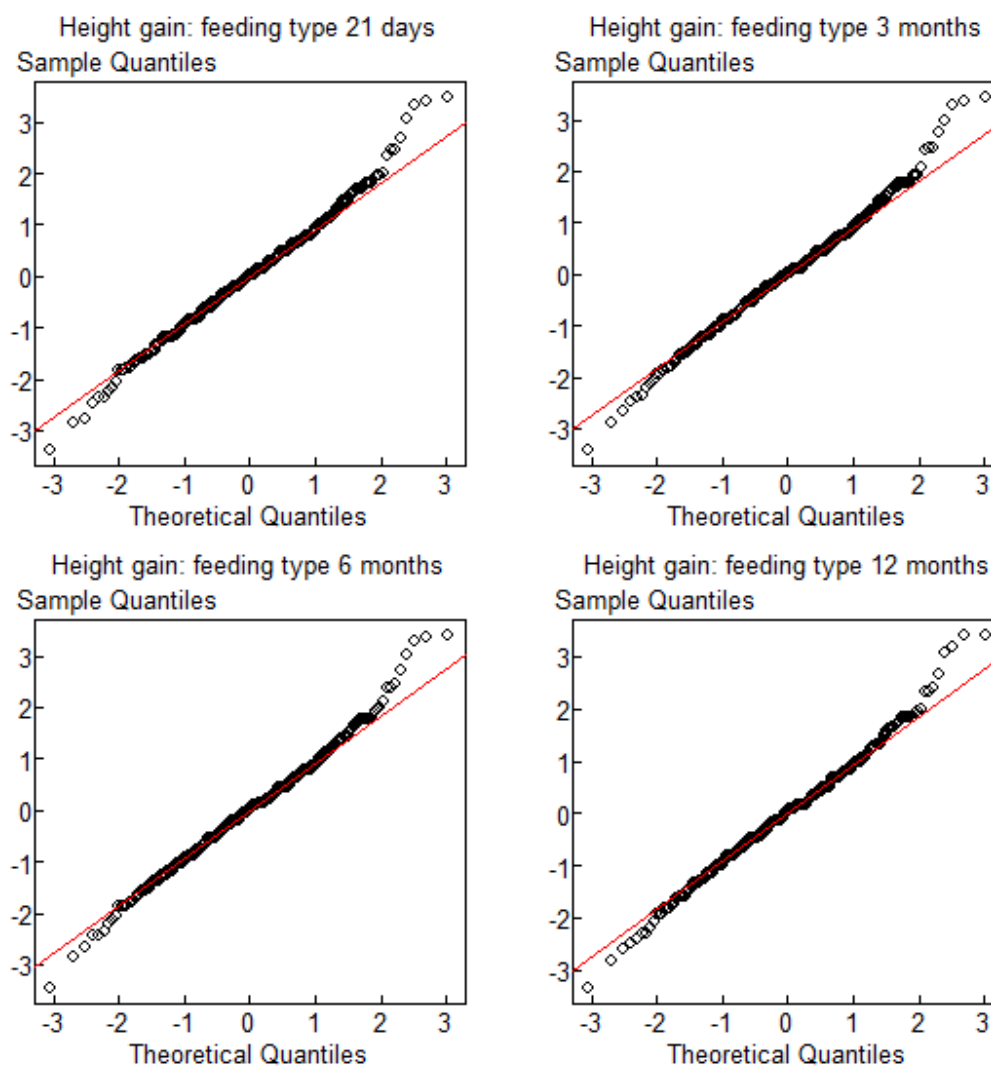


Figure 7: Residual plots from four height gain models at age 1 year for girls on infant feeding type durations

Figure 6 and 7 show plots of residuals versus normal quantiles. Linear regression model is an appropriate method for modeling height gain over the first year of life for boys and girls on infant feeding type durations. This model had acceptable fit with the data.

Figures 8 and 9 show the graph of the 95% confidence intervals of average height gain over the first year of life of boy and girl for each feeding type recorded at four different times (21 days, 3, 6, 12 months) estimated by simple linear model. The red horizontal line in each graph represents the overall mean height gain of both boys and girls over the first year of life. The results show that boys fed by breast milk at aged 3 months had lower height gain than overall mean and fed by formula milk at aged 12 months had higher height gain than overall mean.

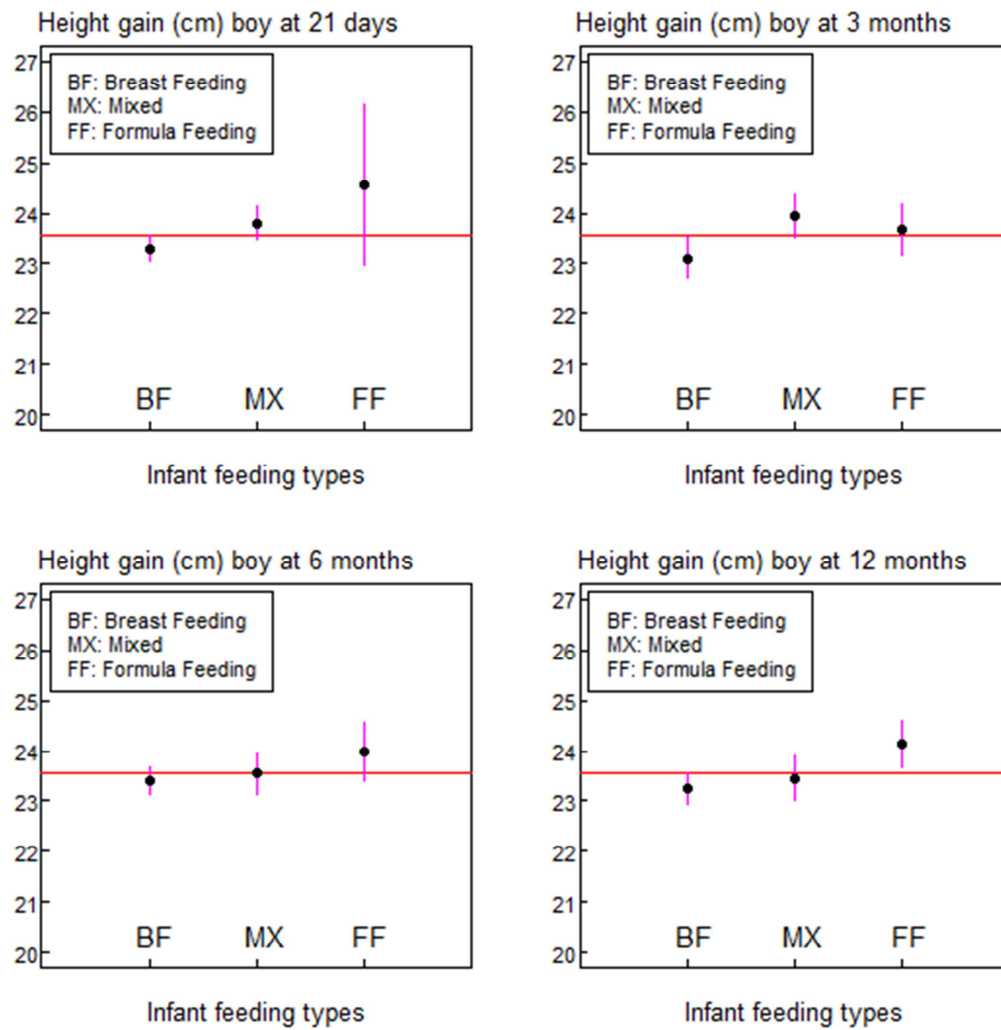


Figure 8: Plots of means and 95% confidence intervals of mean height gain of boys by type of feeding of the infant at four different time periods

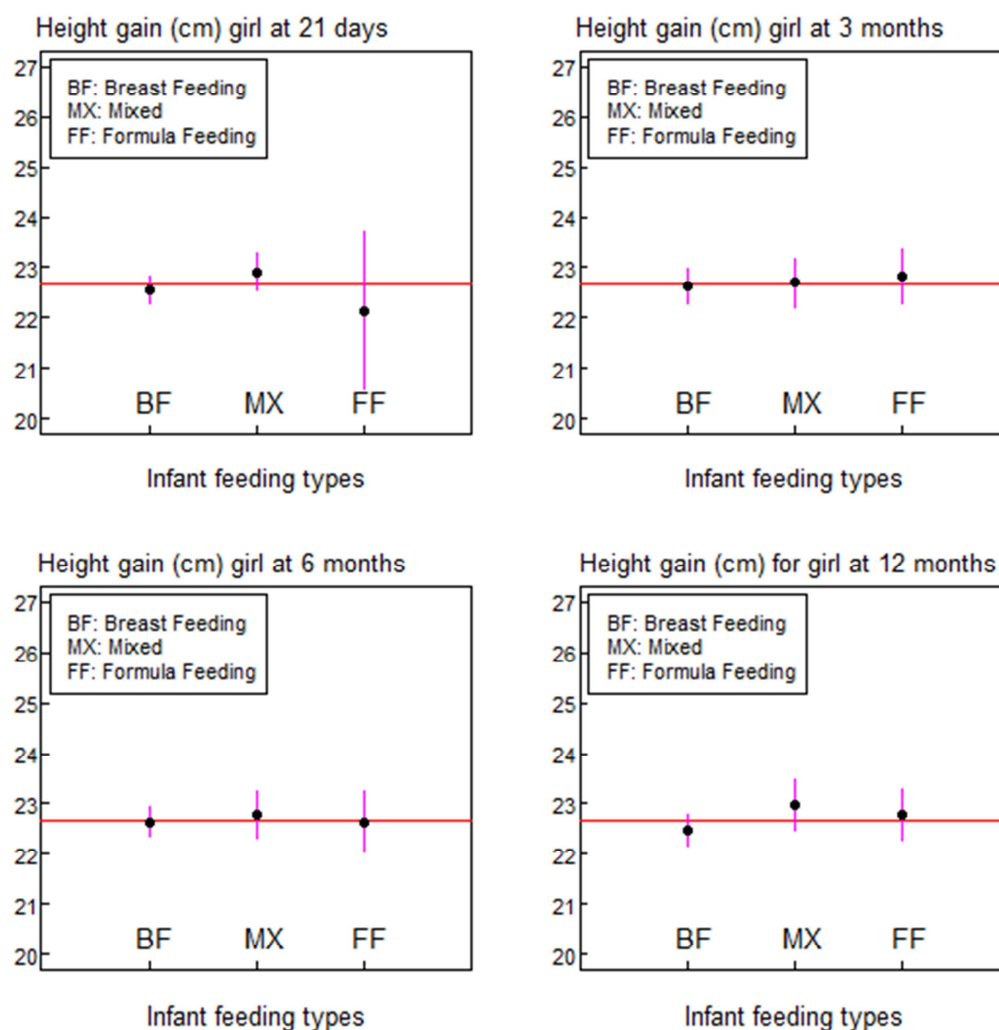


Figure 9: Plots of means and 95% confidence intervals of mean height gain of girls by type of feeding of the infant at four different time periods

DISCUSSION

In the first year of life, infant feeding type duration at aged 21 days, 3, 6 and 12 months were statistical significantly associated with weight gain for both boys and girls. Weight gain fed with breast milk at aged 21 days, 3, 6 and 12 months were statistically significant lower than overall mean whereas weight gain of both boys and girls fed with mixed methods at aged 21 and 3 months and those fed with formula milk at aged 6 and 12 months were statistically significant higher than overall mean.

Boys fed by breast milk at aged 3 months had lower height gain than overall mean and fed by formula milk at aged 12 months had higher height gain than overall mean. Weight gain of boys and girls at aged 1, 3, 5 and 8.5 years fed by breast milk were statistically significant lower than overall mean. Both of boys and girls who were fed with mixed milk had significantly higher height gain than overall mean at aged 3, 5 and 12 years. Height gain of boys at aged 1, 3 and 5 years and girls at aged 3, 5, and 8.5 years fed by breast milk were statistically significant lower than overall mean.

This study provides information on weight gain and height gain of children at aged 1-8.5 years in each category of infant feeding type in different durations. Feeding in infancy at aged 21 days, 3, 6 and 12 months was statistically

significant associated with weight gain in the first year of life. The lower weight gain for children fed by breast milk alone agrees with similar study [10]. This may be normal, because breastfed babies do not grow along the same growth curves as formula fed babies, and it may appear that they grow too slowly. In fact, babies who were fed by formula feeding had growth too quickly [10]. Over the first year of life to aged 8.5 years, babies who were fed with breast feeding had significantly lower weight gain than overall mean. These findings were consistent with results of various studies. For example, study showed that there was a little difference in growth between breast-fed and formula-fed infants [11]. However, from about 2 months of age to the end of the first year of life formula-fed infants gained weight more rapidly than breast-fed infants. Another study presented growth of breast-fed and formula-fed infants compared with national growth references of Thai children [12]. The result from this study showed that Thai children at birth to 6 months who were fed by breast milk and bottle milk had similar mean weight. Thereafter breast-fed infants had lower weight than formula feeding infants with significant difference at 9-12 months in boy infants and at 12 months in girl infants ($p < 0.05$). In contrast, study found that healthy breast-fed infants tended to grow more rapidly than their formula-fed peers in the first 2-3 months of life and less rapidly from 3 to 12 months [13]. Although our study revealed that that weight gain was higher in formula feeding than breast feeding and mixed methods, these findings should generalize with caution. The breastfeeding provide various antibodies for the babies to fight with disease compared to formula feeding. So it is always recommended for babies for breast feeding.

Furthermore, feeding types in infancy was not significantly associated with height gain of children. Studies showed mixed results, in some studies, the height gain was lower among breast-fed infants, whereas in others there was no significant difference in linear growth between feeding groups [14].

In the present study, breast feeding in first year had significantly lower weight gain at aged 1, 3, 5 and 8.5 years than overall mean. Further, children who were fed by mixed methods had significantly higher weight gain at aged 1, 3, 5 and 8.5 years than overall mean. Height gain of both gender who were fed by breast milk had significantly lower than average height gain at aged 1, 3, 5 and 8.5 years for boys and at aged 3, 5 and 8.5 years for girls. However, these findings were not consistent with study [15], who found that the duration of breast-feeding was positively associated with growth in length. The longer the children were breast-fed, the faster they grew during both the second and third years of life. However, there was no association between growth in weight and duration of breast-feeding in rural Senegalese toddlers [15]. Another study reported that there was no significant difference in height, weight and body mass index (BMI) in adolescents who had been breast-fed compared with those who had not been breast-fed [16]. However, by the time these adolescents had reached adulthood, those who had been breast-fed were significantly taller than those who had not been breast-fed (standing height, $P = 0.013$; leg length, $P = 0.035$).

In conclusion, infant feeding type is a significant factor for determining weight gain at first year of life in both boys and girls. Implementation the knowledge of nutrition in infant feeding methods for mothers should be emphasized. Other factors influence growth of children should be included in further studies such as maternal food consumption and maternal smoking during pregnancy. Various statistical methods should be applied for investigating the patterns of child growth.

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