Original Article

New Reference for Neonatal Growth: 10-Year Data of Phramongkutklao Hospital

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Background: Growth assessment including birth weight, length, and head circumference is important to identify infants at risk. However, using international growth curves may be inappropriate for growth assessment of Thai neonates.

Objective: To generate a growth chart of infants at the Phramongkutklao Hospital (PMK), and to compare PMK's growth chart assessment with other international growth charts.

Materials and Methods: The authors generated a PMK growth chart from PMK's newborn database between 2007 and 2016. Birth weight of infants born in 2017 was assessed by using the PMK growth chart in comparison with the Fenton, Lubchenco and Intergrowth Twenty-first growth charts.

Results: To generate a PMK growth chart, 22,926 infants were enrolled to the present study. Comparing with other international growth charts, the Fenton exhibited a higher ninetieth percentile of birth weight than others, especially at gestational age of 36 to 41 weeks. In contrast, the Lubchenco exhibited the lowest tenth percentile of birth weight. In 2017, 2,314 infants were born and evaluated by using the PMK, the Fenton, the Lubchenco, and the Intergrowth-21st growth charts. Large for gestational age (LGA) was identified in 185 (8.64%), 55 (2.57%), 166 (7.75%) and 166 (7.75%) infants, respectively. In contrast, small for gestational age (SGA) was identified in 220 (10.27%), 228 (10.64%), 34 (1.59%) and 148 (6.91%) infants, respectively. The admission rate of infants diagnosed as LGA by PMK, but appropriate for gestational age (AGA) by Fenton was higher than other AGA infants.

Conclusion: The PMK reference of neonatal growth is up-to-date and applicable. Growth assessment using the Fenton growth chart at late preterm and term gestations may be inaccurate to identify LGA infants. In contrast, the Lubchenco growth chart has limitation to identify SGA infants. Data accumulation from multi-centers at different regions of Thailand are warranted to generate a Thai neonatal growth reference.

Keywords: Growth curve, Neonatal growth, Large for gestational age, Small for gestational age

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Growth assessment including birth weight, length, and head circumference is important for routine newborn care to identify infants at risk. Large for gestational age (LGA) and small for gestational age (SGA) are usually classified by birth weight above the ninetieth and below the tenth percentiles, respectively. These LGA and SGA infants are at high risks for postnatal complications requiring special caution and management. Currently, the Lubchenco et al[1], Babson, and Benda[2,3] growth charts, commonly used in the past, have been replaced by Fenton growth chart[4,5] for growth assessment among newborn infants. Recently, the latest Intergrowth-21st chart[6,7], which extensively collected data from infants born at 24 to 43 weeks of gestation in many countries, has been introduced. Although the Fenton[4,5] and the Intergrowth-21st[6,7] growth charts have been recently used world-wide, the accuracy of assessment growth in Thai neonates is questionable.

In Thailand, many studies have demonstrated various fetal and neonatal growth charts[8-16], but none completely examined birth weight, length, and head circumference (Table 1). Most studies were conducted more than 20 years ago among infants born

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Table 1. Studies of Thai neonatal growth charts

Study	Institution/ hospital	Year of data collection	Year of publication	n	Gestational age (week)		Growth parameters		
					Report only 50th percentile	Report 10th, 50th, 90th percentile	Weight	Length	HC
Ratrisawadi and Benalee[8]	QSNICH	1979	1982	306	27 to 32	33 to 41	✓	✓	✓
Khanjanasthiti et al.[9]	Bang Pa-in	1977	1982	1,119	28 to 35	36 to 42	✓	✓	✓
Siripoonya and Tejavej[10]	RA	-	1983	2,419	-	28 to 42	✓	✓	✓
Thaithumyanon et al.[11]	CU	1978 to 1982	1984	1,072	-	28 to 42	✓	✓	✓
Taksaphan et al.[12]	Khon Kaen	1987 to 1989	1990	8,191	-	28 to 42	✓	✓	✓
Suthutvoravut et al.[13]	RA	1981 to 1982	1984	12,934	26 to 30	31 to 44	✓	-	-
Tongsong et al.[14]	CMU	1983 to 1991	1993	1,311	-	28 to 42	✓	-	-
Borisut and Kovavisarach[15]	Rajvithi	2010 to 2013	2014	7,506	-	24 to 42	✓	-	-
Saksiriwuttho et al.[16]	KKU	2005 to 2006	2007	628	-	14 to 41	-	-	✓

HC=head circumference; QSNICH=Queen Sirikit National Institution of Child Health; RA=Faculty of Medicine, Ramathibodi Hospital; CU=Chulalongkorn University; CMU=Chiang Mai University; KKU=Khon Kaen University

at gestational age of more than 28 weeks. Currently, the birth weight of term infants and survival rate of preterm infants born at less than 28 weeks' gestation are increasing. Due to questionable accuracy using international growth charts and changes of neonatal care in Thailand, the authors conducted a study to develop an updated growth chart reference to assess growth of Thai newborn infants.

Materials and Methods

The authors conducted a retrospective study by collecting data of gestational age, gender, birth weight, length, and head circumference from Phramongkutklao (PMK) Hospital newborn database. Inclusion criteria were singleton livebirths admitted to PMK Hospital between 2007 and 2016. Exclusion criteria were infants with multiple births, hydrops fetalis, ambiguous genitalia, congenital anomalies, or chromosomal abnormalities that affected intrauterine growth. The authors generated PMK growth charts of birth weight, length, and head circumference for infants of 23 to 42 weeks' gestation. The PMK growth chart presented the tenth, fiftieth, and ninetieth percentiles of growth parameters to categorize infants as appropriate for gestational age (AGA), LGA, and SGA. In addition, the authors added the third percentile on the curves of head circumference to identify infants with microcephaly.

The authors interpolated graphic curves to compare the tenth, fiftieth, and ninetieth percentiles of birth weight among the PMK, Fenton 2003[4], Lubchenco[1], and Intergrowth-21st (boys)[6,7] growth charts. Similarly, the authors also interpolated the fiftieth percentile of PMK birth weight with other Thai growth charts[8-16].

The present study assessed growth of infants born in 2017 at PMK Hospital using different growth charts and classified them in LGA, AGA, and SGA groups. The authors compared the prevalence of LGA and SGA between using the PMK, Fenton, Lubchenco and Intergrowth-21st growth charts. To determine accuracy in identifying infants at risk, the authors reviewed the rate of admission due to postnatal complications among LGA and SGA infants classified using different growth charts. The research protocol to review growth parameter of infants at 23 to 43 weeks of gestation for making a PMK growth chart reference and for growth chart assessment was approved by the Royal Thai Army Institutional Review Board (IRBRTA 304/2560).

Statistical analysis

Sample size was calculated based on the rate of LGA and SGA infants at 10% and a power of 0.90. The number of infants needed was 3,458. LMS Chart Maker Software was used to smooth the percentile growth curves. Comparisons between the PMK and other graphic curves were created using Microsoft Excel and Graphpad Prism Software. Comparisons for categorical data were analyzed using the chi-square or Fisher's exact test. A p-value of less than 0.05 was considered as statistically significant, and IBM SPSS Statistics, version 22.0 (IBM Corp., Armonk, NY, USA) was used for statistical analysis.

Results

During the 10-year study period, the present study enrolled 23,408 infants from 23 to 43 weeks'

Table 2. Growth parameters of infants for generating the PMK growth chart (n=22,926)

Gestational age (week)	Total number (male)	Growth parameter; mean±SD		
		Weight (g)	Length (cm)	Head circumference (cm)
23	3 (1)	545±126	28.8±2.5	20.5±2.2
24	14 (10)	722±175	31.7±2.6	23.2±2.4
25	6 (6)	767±148	31.9±2.3	23.6±1.1
26	15 (12)	879±197	34.1±2.7	24.4±1.4
27	31 (18)	1,038±199	36.0±3.6	25.6±2.3
28	39 (27)	1,143±212	37.1±2.8	26.1±1.7
29	45 (29)	1,220±224	37.2±2.3	27.1±1.5
30	51 (27)	1,393±293	39.5±2.9	28.0±1.4
31	73 (44)	1,577±338	40.7±3.3	28.5±1.9
32	116 (67)	1,776±401	42.2±3.0	29.9±1.7
33	153 (75)	2,157±509	44.3±3.1	31.0±1.9
34	328 (172)	2,279±412	45.3±2.8	31.6±1.6
35	546 (251)	2,546±437	46.6±2.5	32.4±1.5
36	1,154 (608)	2,715±375	47.4±2.1	32.8±1.3
37	3,910 (2059)	2,912±400	48.2±2.0	33.3±1.3
38	6,745 (3542)	3,085±375	48.9±1.9	33.7±1.2
39	5,500 (2767)	3,187±364	49.4±1.8	33.9±1.2
40	3,434 (1698)	3,307±378	49.9±1.9	34.2±1.2
41	716 (365)	3,349±402	50.1±2.0	34.4±1.2
42	40 (21)	3,286±403	50.0±1.5	34.3±1.0
43	7 (3)	3,109±932	50.4±3.3	33.6±1.8

SD=standard deviation

gestation admitted to PMK. Exclusion criteria were 482 infants with multiple births, hydrops fetalis, ambiguous genitalia, congenital anomalies, or chromosomal abnormalities (Figure 1). In all, 22,926 infants (11,802 boys and 11,124 girls), provided data used to generate a PMK growth chart (Table 2).

To compare with other international growth charts, the authors interpolated the Fenton, Lubchenco, and Intergrowth-21st curves to the PMK growth chart from 23 to 42 weeks' gestation (Figure 2). To compare with other Thai growth charts, the authors selected to present the fiftieth percentile of birth weight from 28 to 41 weeks' gestation (Figure 3).

In 2017, 2,314 newborn infants, admitted to PMK, were assessed using the PMK, Fenton, Lubchenco, and Intergrowth-21st growth charts. The authors focused on 2,142 infants born from 36 to 41 weeks' gestation and categorized in LGA, AGA, and SGA groups (Table 3). Using the PMK, Fenton, Lubchenco, and Intergrowth-21st growth charts, LGA was identified in 185 (8.64%), 55 (2.57%), 166 (7.75%) and 166 (7.75%) infants, respectively.

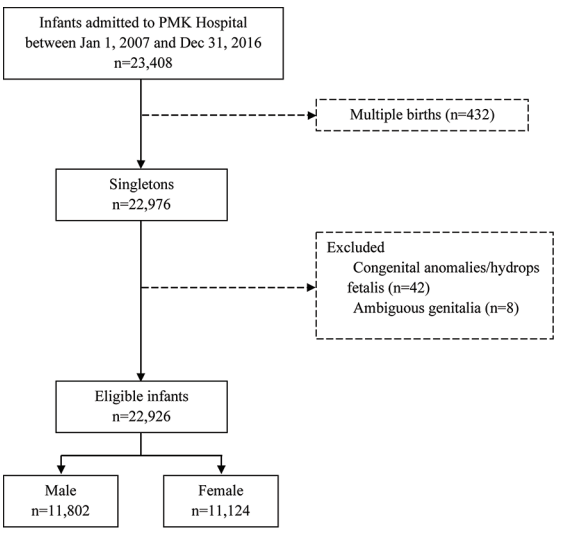

Figure 1. Flow diagram of infants enrolled to the study.

In contrast, SGA was identified in 220 (10.27%), 228 (10.64%), 34 (1.59%) and 148 (6.91%) infants,

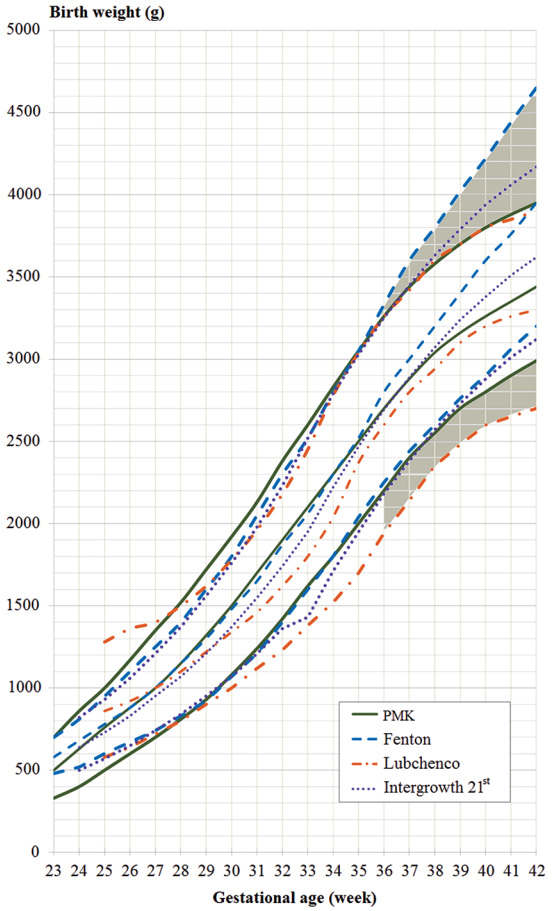

Figure 2. Comparison of birth weight at 90th, 50th, and 10th percentiles between PMK and other international growth charts (Fenton, Lubchenco and Intergrowth-21st).

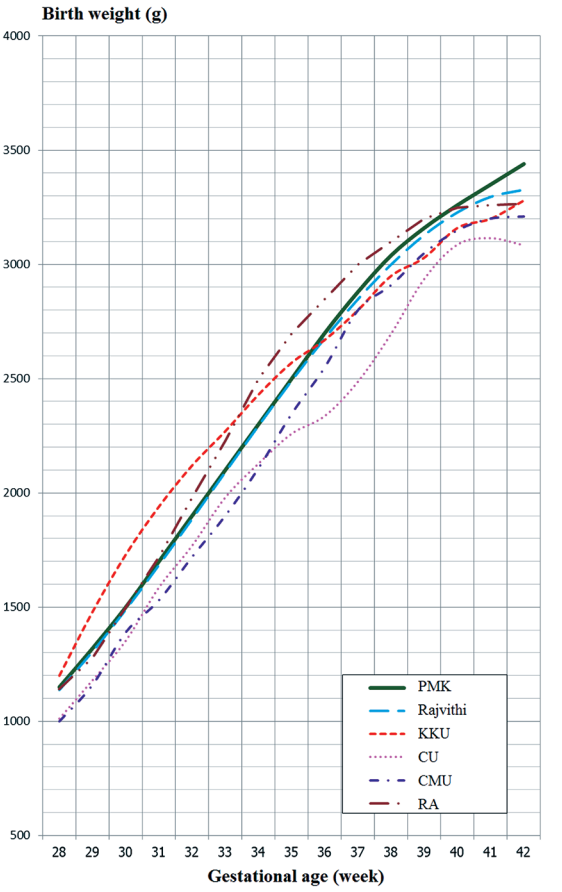

Figure 3. Comparison of birth weight at the 50th percentile between PMK and other Thai growth charts.

PMK=Phramongkutklao Hospital, KKU=Khon Kaen University, CU=Chulalongkorn University, CMU=Chiang Mai University, RA=Ramathibodi Hospital

respectively.

Of the 185 LGA infants, classified using the PMK growth chart, 130 (70.27%) were classified as AGA using the Fenton growth chart. Seventeen (13.08%) and six (4.62%) infants with inconsistent diagnoses were admitted and had transient tachypnea of the newborn (TTN), respectively (Table 4). The rates of admission and TTN were higher than those of other AGA infants but without statistically significant differences (Table 4). Of the 220 SGA infants classified using the PMK growth chart, 186 (84.55%) were classified as AGA using the Lubchenco growth chart (Table 5). However, the admission rate of infants with inconsistent diagnoses (9.14%) was comparable with that of other AGA infants (8.92%) (Table 5).

Discussion

The present study collected data of growth parameters including birth weight, length, and head circumference of the Thai newborn infants born from 23 to 42 weeks' gestation. The authors presented growth charts of all infants including both genders (Figure 4) due to trivial differences of growth parameters between boys and girls. The authors compared the PMK growth chart with that of Fenton 2003[4] and Lubchenco et al[1], which were commonly used in Thailand. In addition, the Fenton combined both genders in the same chart. The authors also compared the PMK growth chart with Intergrowth-21st[6,7], which recently collected data from a large number of neonates in many countries including Asian populations.

Comparing birth weight with the Fenton growth chart[4], the graphic curves of the PMK and Fenton at gestational age less than 36 weeks were comparable. However, after 36 weeks' gestation, the Fenton[4] birth weights were higher than those of the PMK

Table 3. Classification of infants born at 36 to 41 weeks' gestation using PMK, Fenton, Lubchenco and Intergrowth-21st growth charts

Gestational age (week)	n	PMK n (%)	Fenton[4] n (%)	Lubchenco[1] n (%)	Intergrowth-21st[7] n (%)
36	151				
LGA		10 (6.62)	4 (2.65)	9 (5.96)	10 (6.62)
AGA		118 (78.15)	124 (82.12)	139 (92.05)	129 (85.43)
SGA		23 (15.23)	23 (15.23)	3 (1.99)	12 (7.95)
37	356				
LGA		33 (9.27)	11 (3.09)	31 (8.71)	31 (8.71)
AGA		277 (77.81)	297 (83.43)	318 (89.33)	295 (82.87)
SGA		46 (12.92)	48 (13.48)	7 (1.97)	30 (8.43)
38	711				
LGA		57 (8.02)	20 (2.81)	50 (7.03)	60 (8.44)
AGA		582 (81.86)	630 (88.61)	649 (91.28)	605 (85.09)
SGA		72 (10.13)	61 (8.58)	12 (1.69)	46 (6.47)
39	554				
LGA		52 (9.39)	13 (2.35)	47 (8.48)	40 (7.22)
AGA		452 (81.59)	487 (87.91)	501 (90.43)	482 (87.00)
SGA		50 (9.03)	54 (9.75)	6 (1.08)	32 (5.78)
40	320				
LGA		29 (9.06)	7 (2.19)	25 (7.81)	22 (6.88)
AGA		266 (83.13)	277 (86.56)	289 (90.31)	274 (85.63)
SGA		25 (7.81)	36 (11.25)	6 (1.88)	24 (7.50)
41	50				
LGA		4 (8.00)	0 (0.00)	4 (8.00)	3 (6.00)
AGA		42 (84.00)	44 (88.00)	46 (92.00)	43 (86.00)
SGA		4 (8.00)	6 (12.00)	0 (0.00)	4 (8.00)
Total	2,142				
LGA		185 (8.64)	55 (2.57)	166 (7.75)	166 (7.75)
AGA		1,737 (81.09)	1,859 (86.79)	1,942 (90.66)	1,828 (85.34)
SGA		220 (10.27)	228 (10.64)	34 (1.59)	148 (6.91)

PMK=Phramongkutklao; LGA=large for gestational age; AGA=appropriate for gestational age; SGA=small for gestational age

Table 4. Comparison of admission and TTN rates between using PMK and Fenton growth charts to identify LGA among infants of 36 to 41 weeks' gestation (n=185)

	LGA by PMK and Fenton	LGA by PMK but AGA by Fenton	Other AGA infants	p-value*
Total infants	55	130	1,737	
Admission; n (%)	8 (14.55)	17 (13.08)	155 (8.92)	0.114
TTN; n (%)	2 (3.64)	6 (4.62)	37 (2.13)	0.117

PMK=Phramongkutklao; LGA=large for gestational age; AGA=appropriate for gestational age; TTN=transient tachypnea of the newborn

* Comparison between LGA by PMK but AGA by Fenton and other AGA infants

and other growth charts. The Fenton, 2003[4] growth charts comprised much data from many sources[17-19] including post 40-week data from the Centers for Disease Control and Prevention (CDC) chart, which

Table 5. Comparison of admission rate between using PMK and Lubchenco growth charts to identify SGA among infants of 36-41 weeks' gestation (n=220)

	SGA by PMK and Lubchenco	SGA by PMK but AGA by Lubchenco	Other AGA infants	p-value*
Total infants	34	186	1,737	
Admission, n (%)	12 (35.29)	17 (9.14)	155 (8.92)	0.893

PMK=Phramongkutklao; AGA=appropriate for gestational age; SGA=small for gestational age

* Comparison between SGA by PMK but AGA by Lubchenco and other AGA infants

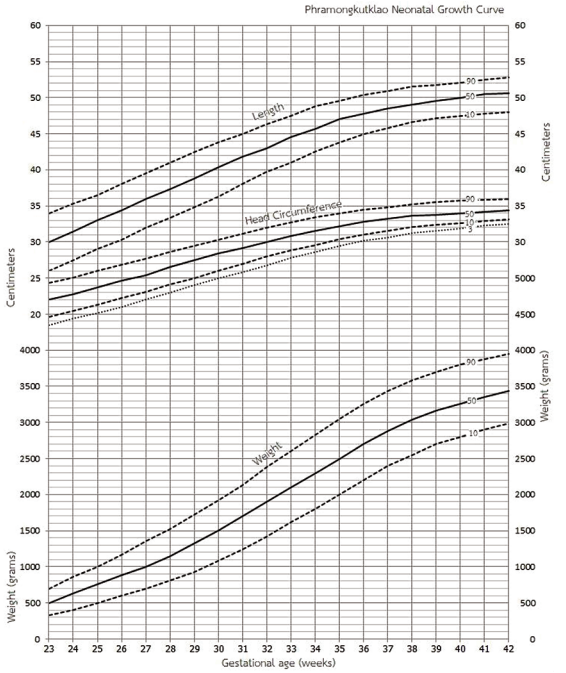

Figure 4. Phramongkutklao (PMK) growth chart with 90th, 50th, and 10th percentiles of length, head circumference and birth weight.

gathered data of the American multiracial-ethnic infants, mostly cross-sectional, but some longitudinal in study design[20]. Methods of collecting data and smoothing the curves at term of gestation probably had the effect of raising the Fenton birth weight curves.

The Lubchenco et al[1] birth weights[1], especially the tenth percentile curve, were lower than those of the PMK and the other studies[4,6,7]. The Lubchenco et al[1] study was conducted 60 to 70 years ago among infants of Colorado, USA. The explanation for lower birth weight in the Lubchenco et al[1] study was probably due to infants born at high altitude, which tend to be smaller than those born at sea level[21].

The Intergrowth-21st growth chart[6,7] exhibits birth weight of boys relatively higher than girls. In the present study, the authors chose the birth weight curve for boys to compare with the other growth charts. The tenth and the ninetieth percentiles of Intergrowth-21st birth weight mostly followed those of the Fenton[4] except for the ninetieth percentile at gestational age more than 35 weeks.

The discrepancies of the ninetieth percentile of birth weight may have resulted in erroneous classification of LGA and missed diagnosis of infants at risk, so the authors reviewed postnatal problems of LGA infants born from 36 to 41 weeks' gestation. The rate of admission and TTN among infants classified as LGA by PMK, but AGA by the Fenton, tended to be higher than those of other AGA infants, though without statistically significant differences between the groups. The authors were unable to review rates of other LGA complications such as hypoglycemia, polycythemia, and birth trauma, due to the limitation of a retrospective study. The authors speculated that birth weight assessment using the Fenton growth chart in late preterm and term infants may have resulted in missed diagnoses of LGA infants at risk. Interestingly, the new Fenton growth charts[5], which were revised systematically, presented growth curves for boys and girls. The ninetieth percentile of boys' birth weight was significantly higher than that of the first Fenton growth chart. Therefore, the discrepancies of LGA classification might be more obvious especially among boys. In addition, using the Fenton growth chart[4,5] for growth monitoring of preterm infants until term gestation may have resulted in overfeeding, which predisposes to childhood obesity and metabolic disorders in later life.

On the other hand, classification of SGA using different growth charts is less problematic except for the Lubchenco growth chart. The admission rate of infants classified as SGA by the PMK, but AGA by the Lubchenco, was comparable with that of other AGA infants. However, one concern is that using the Lubchenco growth chart might result in missed diagnoses of SGA infants at risk of other complications.

Comparing the PMK length and head

circumference curves with those of the Fenton, Lubchenco, and Intergrowth-21st, the curves show similar patterns as birth weight. The authors did not present a length growth curve because of its little benefit for clinical application. Although head circumference is useful to identify infants at risk of nervous system diseases, the present study was retrospective in design and long-term monitoring was not available. When comparing the PMK with the other Thai growth charts[8-16], discrepancies were found of birth weights throughout gestations. From 37 to 42 weeks' gestation, the fiftieth percentile of birth weight in the studies of the Chulalongkorn[11], Khon Kaen[12], and Chiang Mai[14] Universities were lower than that of the PMK growth chart. The differences were probably due to wide variations of data collection regarding years, gestational age, growth parameters, and their percentiles.

The PMK growth chart presents complete growth parameters of infants born over a wide range of gestational ages. However, collecting data from a single institution may not represent growth of Thai neonates born in different regions of Thailand. In addition, the number of infants born at gestational age less than 28 weeks is small when compared with the Fenton and Intergrowth-21st growth charts.

Conclusion

Although growth assessment is mandatory to identify infants at risk, using different growth charts alter the classification and diagnosis of LGA and SGA infants. The authors suggest that the Fenton growth chart might be appropriate for assessing preterm infants because of the largest data collection. For late preterm and term infants, using the PMK and Intergrowth-21st growth charts are safer in identifying both LGA and SGA infants. However, a larger study collecting data from different regions of Thailand would be necessary to generate a Thai neonatal growth chart appropriate to assess the growth of Thai newborn infants.

What is already known on this topic?

The Fenton growth charts are useful and commonly used to assess the growth of preterm infants because of the large number of preterm and term infants in the study.

What this study adds?

The present study shows the limitations of the Fenton growth chart in detecting LGA infants at late preterm and term gestation. On the other hand, the Lubchenco growth chart may underestimate the prevalence of SGA infants. The Intergrowth-21st growth chart seems to have fewer problems in identifying LGA and SGA infants compared with the Fenton and Lubchenco growth charts. However, Thai neonatal growth chart might be more appropriate to assess the growth of Thai newborn infants.

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Conflicts of interest

The authors declare they have no potential conflicts of interest.

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