LIST OF PUBLICATIONS

1) Deeluea J, Sirichotiyakul S, Weerakiet S, Buntha R, Tawichasri C, Patumanond J. Fundal height growth curve for Thai women. ISRN Obstet Gynecol. 2013;2013: 463598.

2) Deeluea J, Sirichotiyakul S, Weerakiet S, Arora R, Patumanond J. Fundal height growth curve for underweight and overweight and obese pregnant women in Thai population. ISRN Obstet Gynecol. 2013;2013:657692.

3) Deeluea J, Sirichotiyakul S, Weerakiet S, Khunpradit S, Patumanond J. Fundal height growth curve patterns of pregnant women with term low birth weight infants. Risk Manag Healthc Policy. 2014;7:131-7.

Appendices

Appendix A

Philosophical context of clinical epidemiology design in this thesis

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Research questions included in this thesis

1. What is the characteristic of standard fundal height growth curve between 20-40 weeks of gestation for Thai women in upper northern Thailand?
2. What is the characteristic of specific fundal height growth curve for subgroups that differ from normal populations?
3. What is the characteristic of fundal height growth curve patterns among pregnant women with term low birth weight infants when compared with the standard fundal height growth curve for Thai women?

Research titles for publication

Study I

Fundal height growth curve for Thai women

Study II

Fundal height growth curve for underweight and overweight and obese pregnant women in a Thai population

Study III

Fundal height growth curve patterns of pregnant women with term low birth weight infants

Clinical epidemiology design

Clinical epidemiology research design includes three components which are theoretical, data collection and data analysis design.

1. Theoretical design

Studies I and II

The objectives of studies 1 and 2 were to create standard and specific FH growth curves between 20 to 40 weeks of gestation to be used to determine relationships between FH and GA from 20 to 40 weeks.

The occurrence relation can be written as follows:

$\text{Fundal height}_i = GA_i \pm IQR$ or

$\text{Fundal height}_i = GA_i \pm 1.96\ (SE)$

Study III

The objective of this study was to investigate the FH growth curve patterns of pregnant women with term low birth weight infants when compared with the standard FH growth curve for Thai women. It comprised the explanation of the characteristic patterns found in those groups. Hence, no relations were observed between variables x and y.

2. Data collection design

Data collection design considered relevancy, validity and precision of the data to detect relations in the study population to follow the exact objectives of the study.

2.1 Study design

All studies in this thesis were retrospective time-series or longitudinal data collections. However, research questions were designed as prospective data collection but consumed more time to collect data due to the need to follow-up time from the beginning until term delivery including FH and GA data between 2009 and 2011, which were reliable enough to use in this study.

2.2 Data collection process

Studies I and II

All data were obtained from Thai women attending antenatal care and delivering at four Ministry of Public Health Hospitals in upper northern Thailand, including two secondary care hospitals: Phayao Hospital and Lamphun Hospital, and two tertiary care hospitals: Lampang Hospital and Nakhon Ping Hospital, between January 2009 and March 2011. All 4 settings had similar patterns of pregnant women for which the majority had middle to poor economic status and followed similar guidelines for antenatal care practices.

Inclusion criteria: normal singleton pregnancy who attended the first antenatal care before 20 weeks of gestation

Exclusion criteria: nonThai, minority groups, unreliable GA, current smokers, consumed alcohol or addictive substance during pregnancy, comorbidity, medical complication during pregnancy; diabetes, hypertension, and anemia, polyhydramnios, oligohydramnios, twins, uterine tumor, intrauterine growth retardation, abnormal fetal presentation, preterm or postterm, low birth weight (<2,500 g), large baby (≥4,000 g), and congenital anomaly.

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Fundal height was measured in centimeters with non-elastic measurement tape from the upper border of the symphysis pubis to the top of the uterine fundus or reversed direction. All measurements were performed by or under supervision of registered nurses or obstetricians who had at least 2 years of experience with obstetric antenatal care to minimize measurement error and bias.

In study II, prepregnancy BMI was calculated from prepregnancy body weight (in kg) divided by square of height (in meters). Pregnant women were categorized in 3 groups based on WHO criteria: obese (BMI ≥30.0 kg/m^2) and overweight (BMI 25.0-29.9 kg/m^2) women were combined, as shown below.

(1) Underweight: BMI <18.5 kg/m^2

(2) Normal weight: BMI 18.5-24.9 kg/m^2

(3) Overweight and obese: BMI ≥25.0 kg/m^2

Study III

Retrospective data of pregnant women with term LBW infants (born weighing <2,500 g, between 37 and 42 completed weeks of gestation) attending ANC and delivering in the four governmental general hospitals in upper northern Thailand between 2009 and 2011 were collected. Foreigners, minority groups, women who first visited ANC later than 20 weeks of gestation, unreliable gestational age and twin pregnancy were excluded from the cohort inception.

All information was extracted from antenatal records, delivery records and other related medical records by the researcher.

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Study I

All analysis was performed using a standard statistical software package.

1. Characteristics of study subjects were presented by frequency, percentages, mean, and standard deviation.
2. Mean and standard deviation of fundal height in centimeters for each gestational week from 20-40 weeks were calculated.
3. Derivation from the standard FH growth curve involved the steps explained below.

3.1 Assessment of gestational age and measurement of FH in centimeters was standardized by correction factor calculated from systematic error by a regression technique because of different methods of GA calculation and settings of FH measurements.

3.2 Distribution and pattern of FH in centimeters between 20 and 40 weeks of gestation were evaluated.

3.3 A second degree polynomial equation or quadratic equation was fitted using a multilevel model for continuous data.

NOTE: Multilevel mixed model was used because FH is a repeated measured performed several times on each pregnant woman when the number of times differed. Furthermore, data from 4 settings led to different FH measurements.

3.4 A quadratic regression model was used to predict the 10^{th}, 50^{th}, and 90^{th} percentiles of fundal height.

3.5 The final quadratic regression model was applied to smooth each percentile line.

3.6 Smoothed curves were drawn from final quadratic regression models.

3.7 The fundal height growth curve was presented as a smoothed function of the 10th, 50th, and 90th percentiles between 20 and 40 weeks of gestation.

Study II

All analysis was performed using a standard statistical software package.

1. The factors that affected FH in centimeters were evaluated using multilevel mixed models regression. The following factors were entered: GA, GA^2, maternal age, prepregnancy BMI, and parity.
2. Characteristics of study subjects were presented by frequency, percentages, mean, and standard deviation. Nonparametric tests for trend were applied to test the differences among the 3 BMI groups.
3. The mean fundal height in centimeters for each gestational week between underweight and normal weight, and between overweight-obese and normal weight pregnant women was compared by t-tests.
4. Derivation the specific FH growth curve for each BMI group followed study I.

Study III

1. The fundal height obtained from the four settings was standardized to correspond to the subjects used in the development of the standard FH growth curve for Thai women.
2. The characteristics of the index group (pregnant women with term LBW infants), and the standard group (normal singleton pregnancy used to develop the standard fundal height growth curve for Thai women) were presented as means, standard deviations or frequencies and percentages. Comparisons across groups were performed using t-tests or exact probability tests. A p-value of <0.05 was considered statistically significant.
3. In the process of screening, serial FH measurements of pregnant women with term LBW infants were plotted against the standard FH growth curve for Thai women displaying the 10^{th}, 50^{th}, and 90^{th} percentile lines, for every ANC visit throughout pregnancy. Criteria for screening are described below.
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References

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Appendix B

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Research Article

Fundal Height Growth Curve for Thai Women

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Objectives. To develop fundal height (FH) growth curve from normal singleton pregnancy based on last menstrual period (LMP) and/or ultrasound dating for women in the northern part of Thailand. *Methods*. A retrospective time-series study was conducted at four hospitals in the upper northern part of Thailand between January 2009 and March 2011. FH from 20 to 40 weeks was measured in centimeters. The FH growth curve was presented as smoothed function of the 10th, 50th, and 90th percentiles, which were derived from a regression model fitted by a multilevel model for continuous data. *Results*. FH growth curve was derived from 7,523 measurements of 1,038 women. Gestational age was calculated from LMP in 648 women and ultrasound in 390 women. The FH increased from 19.1 cm at 20 weeks to 35.4 cm at 40 weeks. The maximum increase of 1.0 cm/wk was observed between 20 and 32 weeks, declining to 0.7 cm/wk between 33 and 36 weeks and 0.3 cm/wk between 37 and 40 weeks. A quadratic regression equation was FH (cm) = −19.7882 + 2.438157 GA (wk) − 0.0262178 GA^2 (wk) (R-squared = 0.85). *Conclusions*. A demographically specific FH growth curve may be an appropriate tool for monitoring and screening abnormal intrauterine growth.

1. Introduction

Routine symphysis-fundal height (or "fundal height" in short) measurement during pregnancy has been used in antenatal care with a long history, to estimate size of uterus and gestational age. It is simple, convenient, safe, and cheap [1–4]. Abnormal fundal height (smaller or larger than gestational age) may indicate abnormal uterus, fetal growth, and amniotic fluid development. Fundus smaller than gestational age may indicate intrauterine growth restriction (IUGR), small for gestational age (SGA), or oligohydramnios, while fundus larger than gestational age may reflect large fetus for gestational age (LGA), polyhydramnios, twins, or uterine tumor [5].

Although ultrasound is replacing fundal height measurement in detecting the above conditions [6, 7], in developing countries, it is not fully available in all antenatal care levels, due to high cost and lack of experienced personnel [1, 3]. Therefore WHO Reproductive Health Library still recommends using fundal height measurement as a tool to estimate gestational age and detect SGA and multiple pregnancies [1]. National Institute for Health and Clinical Excellence Guideline for Antenatal Care (clinical guideline 62) also recommends routine measurement and monitoring fundal height for every antenatal visit [8].

According to Cochrane review, there is not enough evidence to evaluate the use of fundal height measurement during antenatal care [2]; on the other hand, there is also insufficient evidence to determine whether fundal height measurement is not effective [9]. The sensitivity of fundal height measurement in detecting IUGR, SGA, and LGA varies from 17% to 86% [10, 11], due to differences in gestational age assessment and fundal height measurement techniques [3]. Many studies therefore recommend demographically specific fundal height growth curve rather than universally derived curve, as fundal height is influenced by ethnicity, socioeconomics, and nutritional status [12–15].

Fundal height growth curves in Thai women were derived from specific setting with different subject selection and gestational age assessment [16, 17]. Most settings were university hospitals located in Bangkok, while the majority of pregnant women attended the general hospitals or primary care settings and most of them were from middle to low economic status. Gestational age assessment by last menstrual period (LMP) in the past [16] was replaced by ultrasound in more recent studies [17]. Although ultrasound is more accurate during the first half of pregnancy [7], both methods are still applied in most antenatal care services.

We developed fundal height growth curve from normal singleton pregnancy in general hospitals, using gestational age assessment both from LMP and/or ultrasound to reflect routine antenatal care practice. The derived fundal height growth curve is expected to be used in the northern part of Thailand.

2. Subjects and Methods

2.1. Subjects. This was the retrospective time-series study. All data were obtained from Thai women who attended antenatal care and delivered at four university affiliated hospitals in the upper northern part of Thailand, two provincial hospitals and two regional hospitals, between January 2009 and March 2011. Being administered under the Ministry of Public Health of Thailand, the four hospitals have a similar guideline for antenatal care practice. Subject eligible criteria were normal singleton pregnant women who started antenatal care before 20 weeks of gestation. Pregnant women with uncertain gestational age and medical or obstetrical complications affecting fetal growth and those with habitual smoking, alcohol drinking, and drug abuse during pregnancy were excluded from the study.

2.2. Ascertainment of Gestational Age. Gestational age was calculated from (1) first day of LMP if regular menstruation and correlated with size of uterus by palpation or correlated with gestational age by ultrasound (not more than 1 week difference) or (2) ultrasound in the first half of pregnancy if LMP uncontained or size of uterus not correlated with LMP or gestational age by LMP not correlated with ultrasound (more than 1 week difference).

2.3. Fundal Height Measurement. Fundal height was measured in centimeters with nonelastic measurement tape from the upper border of the symphysis pubis to the top of the uterine fundus, or reversed direction. All measurements were performed by or under supervision of registered nurses or obstetricians who had at least 2 years of experience with obstetric prenatal care, in order to minimize measurement error and bias [21].

2.4. Data Collection. Fundal height and gestational age were recorded from the beginning to the end of antenatal care. Labor notes and medical records were reviewed for relevant information.

2.5. Statistical Analysis. Assessment of gestational age and measurement of fundal height were standardized by a correction factor calculated from systematic error by a regression technique. A second-degree polynomial equation was fitted using a multilevel model for continuous data. A quadratic regression model was used to predict the 10th, 50th, and 90th percentiles of fundal height. The final quadratic regression model was applied to smooth each percentile line. The fundal height growth curve was presented as smoothed function of the 10th, 50th, and 90th percentiles between 20 and 40 weeks of gestation. All analysis was done using a standard statistical software package.

2.6. Ethical Approval. The study protocol was approved by the Research Ethics Committee, Faculty of Medicine, Chiang Mai University, and the research ethics committee of the four hospitals.

3. Results

During the study period, there were 2,351 pregnant women who attended antenatal care and delivered at the four hospitals. Normal singleton pregnancies met with eligible criteria in 1,038 subjects. Among these, 696 (67.0%) were from provincial hospitals and 342 (33.0%) from regional hospitals. The proportion of eligible subjects ranged from 20.3% to 60.7%. Characteristics of the study subjects in the provincial and regional hospitals were similar. The average age was 25.6 years (SD = 6.2), body mass index (BMI) was 21.6 kg/m^2 (SD = 3.8), and gestational age at first antenatal visit was 13 weeks (SD = 5.0). The proportion of nulliparity and multiparity were similar. The average of total pregnancy weight gain was 13.5 kg (SD = 4.7), gestational age at delivery was 39.2 weeks (SD = 1.1), and birth weight was 3,120.3 g (SD = 325.0) (Table 1).

Gestational age was calculated from LMP in 648 women (62.4%) and from ultrasound in 390 women (37.6%). Ultrasound was done at the average gestational age of 16 weeks (SD = 5.2). A total of 7,634 fundal height (FH) measurements were used with 111 missing data (1.4%). The remaining 7,523 measurements (98.6%) were analyzed, averaged 7.3 measurements per woman (SD = 2.1) and 358.2 measurements per week (range: 119–840).

The fundal height was likely to be equally distributed across each gestational age (GA) with an obvious monotonous increment from 19.1 cm (SD = 1.9) at 20 weeks to 35.4 cm (SD = 2.4) at 40 weeks (Table 2 and Figure 1). The average increase per week was 0.8 cm. The maximum increase of 1.0 cm/wk was observed between 20 and 32 weeks, declining to 0.7 cm/wk between 33 and 36 weeks and 0.3 cm/wk between 37 and 40 weeks (Table 2).

Table 1: Characteristics of study subjects ($n = 1{,}038$).

Characteristics	N	%
Settings		
Secondary care hospitals	696	67.0
Tertiary care hospitals	342	33.0
Maternal age (year) (mean, ±SD)	25.6	±6.2
Maternal height (cm) (mean, ±SD)	156.1	±5.6
Before pregnancy weight (kg) (mean, ±SD)	52.6	±9.8
Before pregnancy BMI (kg/m^2) (mean, ±SD)	21.6	±3.8
Total weight gain (kg) (mean, ±SD)	13.5	±4.7
Parity		
Nulliparous	523	50.4
Multiparous	515	49.6
GA at first antenatal visit (wk) (mean, ±SD)	13.0	±5.0
GA at delivery (wk) (mean, ±SD)	39.2	±1.1
Type of delivery		
Normal	766	73.8
Cesarean	236	22.7
Vacuum	32	3.1
Forceps	4	0.4
Infant's sex		
Female	479	46.2
Male	559	53.8
Birth weight (gm) (mean, ±SD)	3,120.3	±325.0

GA: gestational age; SD: standard deviation.

The fundal height obtained from quadratic regression equation allowing for random (individual) effect;

$$\text{FH (cm)} = -19.7882 + 2.438157\,\text{GA (wk)} - 0.0262178\,\text{GA}^2\text{ (wk)}. \quad (1)$$

The above equation explained 85% of the variation (R-squared = 0.85).

The final fundal height growth curve (Figure 2) was presented as smoothed function of the 10th, 50th, and 90th percentiles derived from Table 3.

4. Discussion

Our fundal height growth curve was different from previous studies (Table 4) in the aspect of week-specific value, slope, and curve pattern [12–20]. These could be due to differences in ethnicity, socioeconomic, life style, nutritional status, study methodology, eligible criteria, gestational age definition, fundal height measurement, and statistical analysis. Our growth curve has a quadratic pattern similar to studies in Thailand [16, 17], Tanzania [13], and Nigeria [15] but was different from studies in Sweden [12] and Mozambique [14] which had cubic pattern curves. Thai women are relatively smaller and have relatively smaller pelvis compared to Caucasian women [22], causing an increase in a fundal height early in pregnancy (Figure 2). Enlargement of fundal height in Caucasian women with relatively larger and broader pelvis [23] was noticeable later in pregnancy, causing an S-shaped (cubic curve).

Table 2: Mean and standard deviation of fundal height in centimeters for each gestational age based on 1,038 normal singleton pregnancies (7,523 visits).

GA (wk)	Number of measurement	Fundal height (cm)	
		Mean	SD
20	166	19.1	1.9
21	144	20.3	1.8
22	119	21.5	2.1
23	123	22.4	1.8
24	266	23.7	1.7
25	235	24.4	1.8
26	126	25.3	1.7
27	142	26.6	1.7
28	349	27.7	1.8
29	268	28.6	1.8
30	352	29.7	1.7
31	336	30.4	1.7
32	438	31.5	1.6
33	386	32.2	1.7
34	409	33.1	1.6
35	391	33.8	1.7
36	473	34.4	1.7
37	739	34.9	1.9
38	840	35.0	2.0
39	762	35.2	2.3
40	459	35.4	2.4

GA: gestational age; SD: standard deviation.

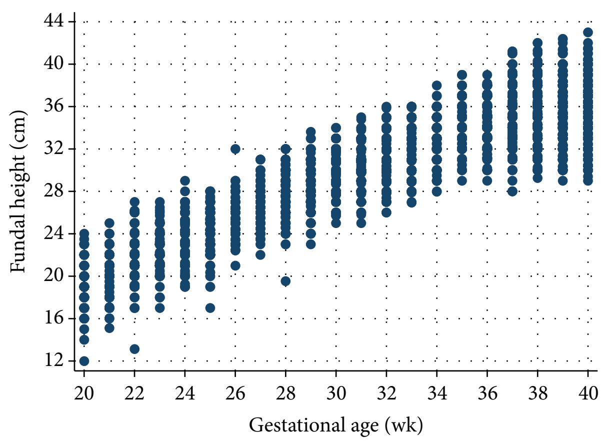

Figure 1: The scatter plot of fundal height (cm) for each gestational age (wk) based on 1,038 normal singleton pregnancies (7,523 visits).

A decline in fundal height around term was caused mainly by fetal engagement. Black women with African ethnicity with anthropoid typed pelvis (long anteroposterior diameter, short transverse diameter) [24] had similar fundal height pattern of growth curve to Thai women but did not decline around term due to unengagement [15]. An exception was observed in some African ethnic with gynecoid pelvis [25].

Table 3: Fundal height at the 10th, 50th, and 90th percentiles in centimeters between 20 and 40 weeks of gestation, derived from a quadratic regression model.

GA (wk)	Number of measurements	Fundal height (cm) Percentiles		
		10th	50th	90th
20	166	16.2	18.7	21.1
21	144	17.6	19.9	22.3
22	119	19.1	21.3	23.6
23	123	20.4	22.5	24.7
24	266	21.7	23.7	25.9
25	235	22.8	24.7	26.8
26	126	24.0	25.9	27.9
27	142	25.1	26.9	28.9
28	349	26.1	28.0	30.0
29	268	26.9	28.8	30.7
30	352	28.0	29.8	31.8
31	336	28.6	30.5	32.5
32	438	29.5	31.4	33.5
33	386	30.1	32.0	34.2
34	409	30.8	32.8	35.0
35	391	31.2	33.4	35.6
36	473	31.8	34.0	36.4
37	739	32.2	34.5	37.0
38	840	32.5	35.0	37.6
39	762	32.8	35.4	38.1
40	459	33.0	35.8	38.6

GA: gestational age.

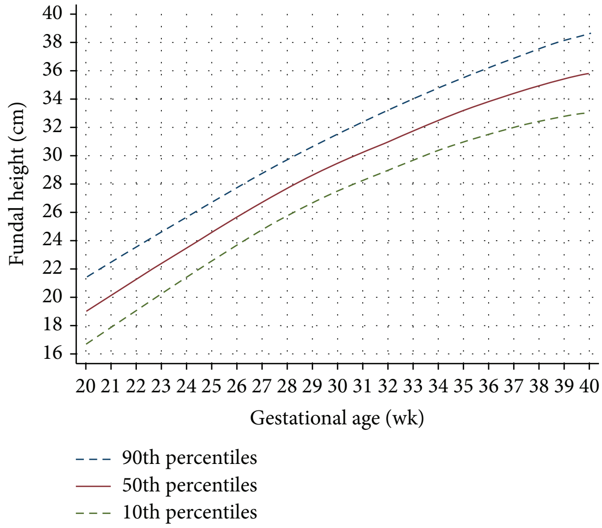

Figure 2: Fundal height growth curve at the 90th, 50th, and 10th percentiles based on 1,038 normal singleton pregnancies (7,523 visits).

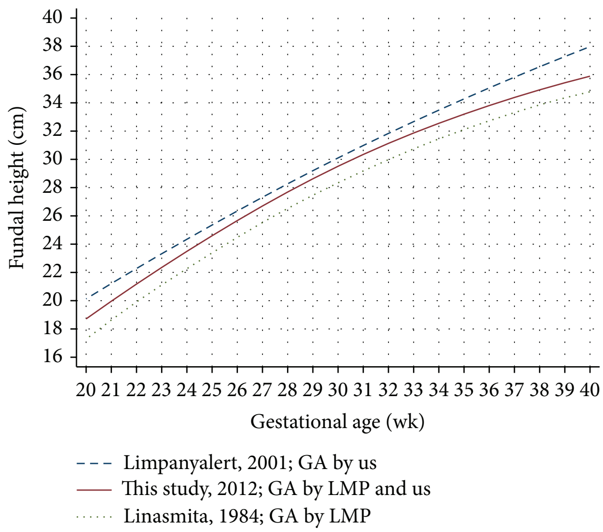

Figure 3: Fundal height growth curves at the 50th percentile derived from Thai women.

Confined to fundal height growth curve in Thai women, our curve is 1.0 cm above the study in 1984 [16], but 0.5 to 1.0 cm below the study in 2001 [17] (Figure 3). The discrepancies may reflect difference population and/or study methodology, including the cohort effect. The fact that mean birth weight in the northern part of the country increased from 2,933 g in 1982 [26] to 3,117 g in 2011 [27] may explain the latter hypothesis.

It is worth noticing that gestational age in three studies used different criteria (Figure 3). Although gestational age by LMP tends to overestimate ultrasound [28, 29], our study had explored and confirmed that gestational age by LMP and by ultrasound was very close. Errors in ultrasound are less in women with low BMI [30]. The fact that our subjects had an average BMI 21.6 kg/m^2 (SD = 3.8) may explain the above statement.

As mentioned above, it is therefore essential that each population should have its own fundal height growth curve to use in screening for abnormal intrauterine growth. Event in the same country, different context of ethnicity, and socioeconomic, measurement method also lead to difference in fundal height growth curve. Our study focuses on development of fundal height growth curve based on routine antenatal care practice in the northern part of Thailand, which may be different from the rest of the country.

The regression technique in our study considered correlation of fundal height and gestational age within the same subject. A multilevel model for continuous data using longitudinally collected data is more appropriate than a cross-sectionally collected data in some studies. Observable larger variation of fundal height early and late pregnancy (Figure 1) may be obscured by thick abdominal wall especially in early pregnancy and fetal engagement beyond 37 weeks.

Existing fundal height growth curve used difference criteria: lower-upper limit, ±1 to ±2 standard deviation, and the 10th to 90th percentile or 5th to 95th percentile. We chose

Table 4: Fundal height growth curves from existing studies.

Source	Country	Number of women	Number of visits	LMP/US	Subjects	GA (wk) and FH (cm)					
						20	24	28	32	36	40
Calvert et al., 1982 [18]	UK	313	1,775	LMP	Normal	18.8	22.9	26.8	30.2	33.7	36.2
Linasmita and Sugkraroek, 1984 [16]	Thailand	415	1,295	LMP	Normal	17.7	23.1	26.4	30.4	32.9	34.6
Ngan et al., 1988 [19]	Hong Kong	—	1,051	LMP	—	17.9	22.0	25.9	29.5	32.8	36.1
Rai et al., 1995 [20]	India	100	523	LMP	Normal	18.9	22.8	26.9	31.0	34.4	37.3
Hakansson et al., 1995 [12]	Sweden	403	4,189	LMP and US	Normal	19.0	23.0	27.0	30.5	33.5	35.5
Walraven et al., 1995 [13]	Tanzania	83	403	LMP	Normal	16.2	20.3	23.6	27.8	31.2	33.6
Limpanyalert and Manotaya, 2001 [17]	Thailand	199	879	US	Normal	20.1	24.2	28.7	32.0	35.8	36.9
Challis et al., 2002 [14]	Mozambique	817	6,544	US	All	19.0	23.0	26.8	30.0	33.0	35.0
Mador et al., 2010 [15]	Nigeria	405	405	US	—	19.1	24.4	28.3	32.0	35.8	39.3
This study, 2012	Thailand	1,038	7,523	LMP and US	Normal	18.6	23.7	27.9	31.4	34.0	35.8

GA: Gestational age; FH: fundal height; LMP: GA by last menstrual period; US: GA by ultrasound.

the 10th to 90th percentile to focus on screening rather than diagnosis. We also recommend monitoring fundal height at every antenatal visit. Medical consultation or further investigation is recommended when fundal height is below the 10th, or above 90th percentile; fundal height growth rate decelerates, stabilizes or declines, or increases rapidly.

Screening for abnormal uterine growth and gestational age in the past assumed a constant linear equation; FH (cm) = GA (wk) ±2, for pregnancy 20–36 weeks. There was a strong statistical evidence that our data fitted more appropriately with a quadratic pattern ($P < 0.001$ from likelihood-ratio test).

However, one should be aware that fundal height measurement is more or less subjective to error, either from intra- or interobservers. To minimize such limitation, standardization and regular calibration should be emphasized.

Being a retrospective data collection, some of the data were inevitably incomplete. Our study, however, tried to collect a large sample sized data to allow for missing values.

Like other clinical prediction rules, the derived fundal height growth curve should be validated before putting into routine clinical practice.

5. Conclusions

A demographically specific fundal height growth curve is a simple tool for monitoring intrauterine growth and screening for abnormal uterine growth. Applying fundal height growth curve into routine antenatal care practice may reduce unnecessary ultrasound in fully equipped settings and reduce unnecessary referring for further investigations in resource-deprived settings.

Conflict of Interests

The authors declare no conflict of interests.

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Research Article

Fundal Height Growth Curve for Thai Women

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Appendix C

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Clinical Study

Fundal Height Growth Curve for Underweight and Overweight and Obese Pregnant Women in Thai Population

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Objectives. To develop fundal height growth curves for underweight and overweight and obese pregnant women based on gestational age from last menstrual period and/or ultrasound. *Methods*. A retrospective study was conducted at four hospitals in the northern part of Thailand between January 2009 and March 2011. Fundal height, gestational age, height, and prepregnancy weight were extracted from antenatal care and delivery records. Fundal height growth curves were presented as smoothed function of the 10th, 50th, and 90th percentiles between 20 and 40 weeks of gestation, derived from multilevel models. *Results*. Fundal height growth curve of the underweight was derived from 1,486 measurements (208 women) and the overweight and obese curve was derived from 1,281 measurements (169 women). The 50th percentile line of the underweight was 0.1–0.4 cm below the normal weight at weeks 23–31 and 0.5–0.8 cm at weeks 32–40. The overweight and obese line was 0.1–0.4 cm above the normal weight at weeks 22–29 and 0.6–0.8 cm at weeks 30–40. *Conclusions*. Fundal height growth curves of the underweight and overweight and obese pregnant women were different from the normal weight. In monitoring or screening for abnormal intrauterine growth in these women, fundal height growth curves specifically developed for such women should be applied.

1. Introduction

A demographically specific fundal height (FH) growth curve derived from local pregnant women with specific ethnicity, socioeconomics, or nutritional status [1] is likely to be suitable for monitoring and screening abnormal intrauterine growth in developing countries, especially in areas where ultrasound is not available. It is simple, convenient, safe, inexpensive [2–4], and may reduce transferring rate and may avoid unnecessary ultrasound [5].

However, previous findings showed that in women of the same geographical areas, there were still other independent determinants of FH. These determinants included maternal height, maternal weight, body mass index (BMI), parity, fetal sex, and gestational age (GA) [6–8]. The determinant that most influenced the difference in the pattern of FH growth curve was body shapes of pregnant women (obese-slim or large-small BMI). Given the same GA, FH of obese women was 2 cm higher than that of slim women [7, 8].

Application of FH growth curve derived from "general" population to monitor or screen abnormal intrauterine growth in obese or slim women may result in over- or underinvestigation and/or intervention. Applying separate FH growth curves specific for women body shapes may be more beneficial [7].

In Thailand, separate FH growth curves according to prepregnant BMI, <20, 20–24, and >24 kg/m^2, and GA assessed from ultrasound [7], were proposed. However, BMI categorization and GA assessment were not based on routine antenatal care practice in most hospitals, in which categorizing BMI followed world health organization (WHO), <18.5, 18.5–24.9, 25.0–29.9, and ≥30.0 kg/m^2 [9], and GA was routinely assessed by last menstrual period (LMP) and/or ultrasound, based on individual judgment [1]. The proposed FH growth curves were therefore unlikely to be used in routine practice.

The present study aimed to develop fundal height growth curves for underweight (BMI < 18.5 kg/m^2) and overweight and obese (BMI ≥ 25.0 kg/m^2) pregnant women in the northern part of Thailand, based on GA from LMP and/or ultrasound following routine practice.

2. Subjects and Methods

2.1. Pregnant Women. Antenatal care (ANC) and delivery records of women between January 2009 and March 2011 were retrospectively collected from two secondary care and two tertiary care hospitals in the northern part of Thailand.

The study included women whose GA was less than 20 weeks when attending the first ANC visit. The following pregnant women were excluded: non-Thai, minority groups, unreliable GA, those with comorbidity, current smokers, those who used alcohol or addictive substance during pregnancy, those who developed medical complication during pregnancy: diabetes, hypertension, and anemia, those who had twins, uterine tumor, polyhydramnios, oligohydramnios, intrauterine growth restriction, abnormal fetal presentation, preterm or postterm, low birth weight (<2,500 g) or relatively large baby (≥4,000 g), or congenital anomaly.

2.2. Prepregnancy Body Mass Index. Prepregnancy BMI was calculated from prepregnancy body weight (in kg) divided by square of height (in meter).

Pregnant women were categorized into 3 groups based on WHO criteria [9]. Obese (BMI ≥ 30.0 kg/m^2) and overweight (BMI 25.0–29.9 kg/m^2) women were combined, as follows.

(1) Underweight: BMI < 18.5 kg/m^2

(2) Normal weight: BMI 18.5–24.9 kg/m^2

(3) Overweight and obese: BMI ≥ 25.0 kg/m^2.

2.3. Ascertainment of Gestational Age. Gestational age was assessed from 2 sources: (1) based on first day of LMP in women with regular menstruation history, who could recall the exact date and those whose FH was correlated with GA, or GA by LMP was no more than 1 week different from ultrasound, (2) from ultrasound performed in the first half of pregnancy, in women who did not fulfill criteria (1).

2.4. Fundal Height Measurement. The measurement of FH followed routine practice of the four settings, which was adopted from ANC practice recommended by The Division of Maternal and Child Health and The Ministry of Health. All measurements were conducted by nurses or physicians in ANC clinics who had at least 2 years of experiences. This was based on the finding that such experiences reduced measurement errors and bias [10].

2.5. Data Collection and Data Sources. Key information included GA, FH, height, and prepregnancy weight. All information was extracted from ANC records, delivery records, and other related medical records.

2.6. Statistical Analysis. Data analysis was done considering the differences of GA calculated by different methods and the differences in FH measurements by different settings and by standardization methods.

The general characteristics of pregnant women were presented by frequency, percentages, mean, and standard deviation. Nonparametric tests for trend were applied to test the differences among the 3 BMI groups.

The mean FH (cm) for each gestational week between underweight and normal weight and between overweight and obese and normal weight pregnant women was compared by t-tests.

Polynomial equations of the 10th, 50th, and 90th percentiles of FH on GA among the underweight, normal weight, and overweight and obese pregnant women were conducted by multilevel models for continuous data. Smoothed curves were drawn from final quadratic regression models.

2.7. Ethical Approval. The study protocol was approved by the Research Ethics Committee, Faculty of Medicine, Chiang Mai University, and the research ethics committee of the four hospitals.

3. Results

Study subjects were comprised of 1,038 pregnant women, categorized by BMI into underweight (n = 208, 20.0%), normal weight (n = 661, 63.7%), and overweight and obese (n = 169, 16.3%). The three groups were different in maternal age, maternal height, prepregnancy weight, total weight gain, parity, birth weight, GA at first ANC and ultrasound, and frequency of ANC ($P < 0.05$). Gestational age at delivery, infant's sex, settings, and GA assessment methods were similar (Table 1).

3.1. Underweight Pregnant Women. In this group, FH increased from 19.1 cm (±1.7) at 20-week GA to 34.5 cm (±2.3) at 40-week GA. The average increasing rate was 0.8 cm/wk. The highest rate was observed at 1.0 cm/wk between 20 and 32 weeks, declining to 0.6 cm/wk between 33 and 36 weeks, and to 0.2 cm/wk between 37 and 40 weeks (Table 2).

3.2. Normal Weight Pregnant Women. The FH in this group increased from 19.1 cm (±1.9) at 20-week GA to 35.4 cm (±2.3) at 40-week GA. The average rate was 0.8 cm/wk, highest between 20 and 32 week at 1.0 cm/wk, declining to 0.8 cm/wk

Table 1: Characteristics of pregnant women.

Characteristics	Underweight (<18.5) (n = 208; 1,486 visits) Mean	±SD	Normal weight (18.5–24.9) (n = 661; 4,756 visits) Mean	±SD	Overweight and obese (≥25.0) (n = 169; 1,281 visits) Mean	±SD	Global P value*
Maternal age (year)	22.8	±5.0	25.9	±6.3	28.1	±5.7	<0.001
Maternal height (cm)	157.5	±6.1	155.6	±5.4	156.1	±5.6	0.011
Prepregnancy weight (kg)	42.9	±4.0	51.5	±5.4	69.0	±8.0	<0.001
Prepregnancy BMI (kg/m^2)	17.3	±1.1	21.2	±1.8	28.3	±2.7	<0.001
Total weight gain (kg)	13.9	±4.0	13.9	±4.5	11.2	±5.2	<0.001
Gestational weight gain** (n, %)							<0.001
Less than recommended	79	38.0	197	29.9	27	16.0	
Within recommended	99	47.6	273	41.4	56	33.1	
More than recommended	30	14.4	189	28.7	86	50.9	
Parity (n, %)							<0.001
Nulliparous	143	68.7	333	50.4	47	27.8	
Multiparous	65	31.3	328	49.6	122	72.2	
GA at delivery (wk)	39.1	±1.1	39.2	±1.1	39.3	±1.1	0.107
Infant's sex (n, %)							0.918
Female	101	48.6	294	44.5	84	49.7	
Male	107	51.4	367	55.5	85	50.3	
Birth weight (gm)	3,035.0	±318.4	3,126.5	±327.0	3,201.0	±302.3	<0.001
Settings (n, %)							0.754
Secondary care hospitals	140	67.3	445	67.3	111	65.7	
Tertiary care hospitals	68	32.7	216	32.7	58	34.3	
Gestational age by (n, %)							0.051
LMP	115	55.3	424	64.2	109	64.5	
Ultrasound	93	44.7	237	35.8	60	35.5	
GA at first ANC (wk)	14.2	±5.2	12.7	±4.8	12.6	±4.9	0.001
GA at ultrasound (wk)	16.9	±5.4	15.8	±5.1	15.2	±5.3	0.037
Frequency of ANC (per woman)	6.9	±2.2	7.3	±2.1	7.5	±2.2	0.020

Prepregnancy BMI (kg/m^2) spans the three BMI groups.

BMI: body mass index; GA: gestational age; LMP: last menstrual period; ANC: antenatal care.
*P value from nonparametric tests for trend.
**Recommendations by the Institute of Medicine (2009) [11]: underweight prepregnancy BMI (<18.5 kg/m^2) = 12.5–18 kg; normal weight (18.5–24.9 kg/m^2) = 11.5–16 kg; overweight (25.0–29.9 kg/m^2) = 7–11.5 kg; obese (≥30.0 kg/m^2) = 5–9 kg.

between 33 and 36 weeks, and to 0.2 cm/wk between 37 and 40 weeks (Table 2).

3.3. Overweight and Obese Pregnant Women. In this last group, FH increased from 19.2 cm (±2.0) at 20-week GA to 36.2 cm (±2.2) at 40-week GA. The average rate was 0.9 cm/wk, highest between 20 and 32 week at 1.1 cm/wk, declining to 0.7 cm/wk between 33 and 36 weeks, and to 0.2 cm/wk between 37 and 40 weeks (Table 2).

3.4. Underweight versus Normal Weight Pregnant Women. At 20 weeks, the FH of the two groups was similar. However, between 33 and 36 weeks, the increasing rate in the underweight was 0.2 cm/wk lower than in the normal weight group, resulting in a difference of 0.9 cm at week 40. Week by week comparisons showed significant differences between weeks 34 and 40 (Table 2).

3.5. Overweight and Obese versus Normal Weight Pregnant Women. At 20 weeks, the two groups were also similar in FH. The increasing rate in overweight and obese was 0.1 cm/wk higher until week 32, resulting in a 0.8 cm difference at week 40. Through comparisons by weeks, the FH was significantly different between weeks 30 and 40 (Table 2).

3.6. Fundal Height Growth Curve. The FH obtained from quadratic equations allowing for random (individual) effect was estimated by the following equations.

Underweight:

$$\text{FH (cm)} = -19.04386 + 2.40662\,\text{GA (wk)} - 0.026439\,\text{GA}^2\ \text{(wk)}. \quad (1)$$

Normal weight:

$$\text{FH (cm)} = -19.61757 + 2.426414\,\text{GA (wk)} - 0.0260198\,\text{GA}^2\ \text{(wk)}. \quad (2)$$

Table 2: Mean and standard deviation of fundal height (in centimeters) for each gestational age in underweight, normal weight, and overweight and obese pregnant women.

GA (wk)	Fundal height (cm)							
	Underweight (n = 208; 1,486 visits)		Normal weight (n = 661; 4,756 visits)		P value*	Overweight and obese (n = 169; 1,281 visits)		P value**
	Number	Mean ± SD	Number	Mean ± SD		Number	Mean ± SD	
20	35	19.1 ± 1.7	104	19.1 ± 1.9	0.933	27	19.2 ± 2.0	0.867
21	31	20.3 ± 1.8	90	20.4 ± 1.9	0.780	23	20.2 ± 1.8	0.628
22	23	21.4 ± 2.5	72	21.3 ± 2.1	0.874	24	21.9 ± 1.6	0.276
23	25	22.7 ± 1.6	83	22.4 ± 1.9	0.444	15	22.4 ± 1.9	0.901
24	53	23.2 ± 1.7	167	23.8 ± 1.6	0.020	46	23.8 ± 2.1	0.959
25	51	24.4 ± 1.9	145	24.4 ± 1.8	0.808	39	24.5 ± 1.7	0.896
26	22	24.9 ± 1.5	73	25.2 ± 1.5	0.350	31	25.9 ± 2.0	0.054
27	32	26.3 ± 1.5	90	26.7 ± 1.7	0.259	20	26.8 ± 2.0	0.957
28	62	27.1 ± 1.8	225	27.7 ± 1.7	0.034	62	28.1 ± 1.8	0.077
29	54	28.3 ± 1.9	167	28.7 ± 1.8	0.138	47	28.8 ± 1.8	0.692
30	66	29.1 ± 1.7	223	29.7 ± 1.6	0.018	63	30.5 ± 1.4	0.001
31	73	30.1 ± 1.7	209	30.4 ± 1.7	0.240	54	30.9 ± 1.5	0.050
32	87	31.0 ± 1.7	278	31.4 ± 1.6	0.045	73	32.2 ± 1.5	<0.001
33	70	31.8 ± 1.7	249	32.1 ± 1.7	0.231	67	32.9 ± 1.4	<0.001
34	89	32.4 ± 1.8	249	33.2 ± 1.5	<0.001	71	33.6 ± 1.6	0.048
35	73	33.3 ± 1.5	251	33.7 ± 1.6	0.082	67	34.6 ± 1.7	<0.001
36	94	33.7 ± 1.8	297	34.5 ± 1.5	<0.001	82	34.9 ± 1.8	0.061
37	145	34.0 ± 2.0	481	34.9 ± 1.8	<0.001	113	35.7 ± 1.7	<0.001
38	164	34.4 ± 2.0	529	35.0 ± 1.8	0.003	147	36.0 ± 2.1	<0.001
39	151	34.3 ± 2.0	495	35.2 ± 2.3	<0.001	116	36.1 ± 2.3	<0.001
40	86	34.5 ± 2.3	279	35.4 ± 2.3	0.002	94	36.2 ± 2.2	0.002

GA: gestational age.
*Underweight versus normal weight.
**Overweight and obese versus normal weight.

Overweight and obese:

$$FH\ (\text{cm}) = -21.77403 + 2.552643\,GA\ (\text{wk}) - 0.0272487\ GA^2\ (\text{wk}). \tag{3}$$

The above equations explained 84%, 86%, and 87% of the variation (R-squared = 0.84, 0.86, and 0.87, resp.).

The final FH growth curve of underweight, normal weight, and overweight and obese pregnant women (Figure 1) was presented as smoothed functions of the 10th, 50th, and 90th percentiles derived from Table 3.

Overall comparisons of the FH growth curves among the underweight, the normal weight, and the overweight and obese pregnant women showed that the 50th percentiles of the three groups departed at weeks 22-23. The departures were more obvious at weeks 30–32. The underweight line was 0.1–0.4 cm below the normal line at weeks 23–31 and 0.5–0.8 cm at weeks 32–40. In the opposite direction, the overweight and obese line was 0.1–0.4 cm above the normal line at weeks 22–29 and 0.6–0.8 cm at weeks 30–40 (Figure 1).

Table 3: Coefficients at the 10th, 50th, and 90th percentiles for fundal height prediction equations in underweight, normal weight, and overweight and obese pregnant women from multilevel models.

Parameters	Coefficient (cm)		
	10th percentiles	50th percentiles	90th percentiles
Underweight			
Constant	−22.31506	−18.08827	−16.36419
GA (wk)	2.550561	2.345531	2.314052
GA^2 (wk)	−0.029636	−0.025478	−0.024279
Normal weight			
Constant	−28.94898	−19.02109	−10.01752
GA (wk)	2.943811	2.392514	1.914523
GA^2 (wk)	−0.034877	−0.025569	−0.017541
Overweight and obese			
Constant	−26.51847	−22.88809	−13.76647
GA (wk)	2.769345	2.639944	2.115199
GA^2 (wk)	−0.031173	−0.028917	−0.019630

GA: gestational age.

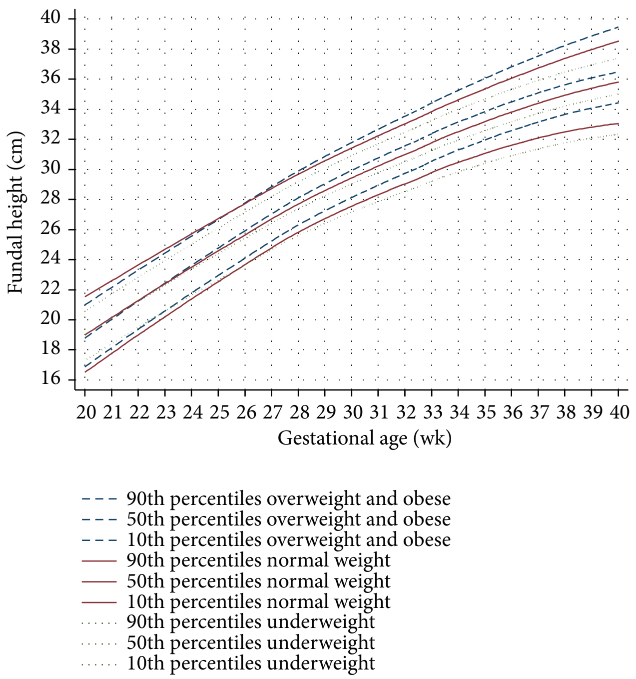

Figure 1: Fundal height growth curve at the 90th, 50th, and 10th percentiles derived from 169 overweight and obese pregnant women (1,281 visits) (dash lines), 661 normal weight pregnant women (4,756 visits) (solid lines), and 208 underweight pregnant women (1,486 visits) (dot lines).

The 90th percentile line of the underweight was below the normal weight throughout pregnancy, approximately by 0.4–1.2 cm. The 10th percentile line of the overweight and obese was above the normal weight throughout pregnancy, with the average of 0.4–1.4 cm (Figure 1).

4. Discussion

The FH growth curves for the underweight, normal weight, and overweight and obese pregnant women were different regarding the 10th, 50th, and 90th percentiles and the inclining rates per week (Figure 1).

4.1. Abdominal Subcutaneous Fat Thickness. Abdominal subcutaneous fat thickness or subcutaneous adipose tissue thickness is directly correlated with FH as FH was measured with nonelastic tapes. Women with abdominal subcutaneous fat thickness were likely to have higher FH than those with thinner abdominal subcutaneous fat. Subcutaneous adipose tissue thickness of anterior abdomen in nonpregnant women with BMI <25, 25–29.9, 30–39.9, and ≥40 kg/m^2 increased from 10.6 to 17.6, 22.4, and 26.8 mm [12]. Similar correlation was also reported in pregnant women [13]. However, age and number of pregnancies were not directly correlated with abdominal subcutaneous fat thickness [14].

4.2. Fetal Weight and Birth Weight. Fetal weight and birth weight (BW) were directly correlated with FH [15, 16] as the size of the uterus expanded to compensate the size of fetus, placenta, and amniotic fluid [17]. Our study excluded pregnancies with any of the above abnormal conditions, as there had been reports that they interfered with FH measurements. As the BW among the three study groups was different (Table 1), this should explain the difference in FH measurements. Beyond these explanations, other determinants of fetal weight and BW were as follows.

4.2.1. Prepregnancy BMI. Prepregnancy BMI influenced fetal weight and BW [18, 19]. Body mass index at the beginning of pregnancy may be considered as a surrogate for the nutritional status of the mothers [20]. In pregnant women with high BMI, altered metabolic hormones, increased placental nutrient transport capacity, and increased nutrient delivery to fetus may result in relatively large fetus. The opposite findings were observed in pregnant women with low BMI [21]. Maternal BMI was also reported to influence fetal growth during the third trimester [20, 22] as a consequence of lowering serum concentrations of insulin-like growth factor binding protein-1 (IGFBP-1) resulting in increased fetal growth [21]. Our study also noticed the more inclining FH among the overweight and obese women (Figure 1).

4.2.2. Gestational Weight Gain. Gestational weight gain was correlated with BW [19, 23]. Large for gestational age fetus or high birth weight infant was common in women with high gestational weight gain. The opposite, small for gestational age fetus or low birth weight infant was also common in women with low gestational weight gain [19, 24], as assessed by the Institute of Medicine (IOM) criteria [11]. The overweight and obese women in our study gained 50.9% more weight than that recommended by the IOM and the underweight women also gained 38.0% less than recommended (Table 1).

4.2.3. Parity. Parity or birth order was positively correlated with BW [25, 26]. Later orders of pregnancy carry residual weight gain and adipose tissue deposit from previous pregnancies. Many studies also reported correlations between parity and both BMI and obesity [27, 28], such that high BW was more prevalent in multiparity and obese women.

4.2.4. Maternal Age. The effect of maternal age on BW varied between studies. Some studies claimed no correlation [29] while some studies reported that age in combination with parity influenced BW, for example, higher parity at younger maternal ages, particularly 15–19 year olds having their second or third birth, appeared to have adverse effects on birth weight [26]. Age may therefore be an effect modifier for BW. In our study, maternal ages of the three weight groups were also different (Table 1). Most of the overweight and obese group was multiparous (72.2%) with the average age of 28.9 ± 5.7 yrs, while most of the underweight group was nulliparous (68.7%) with the average age of 22.4 ± 4.9 yrs.

The above dissimilarities indicated the necessity to develop FH growth curves specifically for women with different body structures. Women with “average” body structure

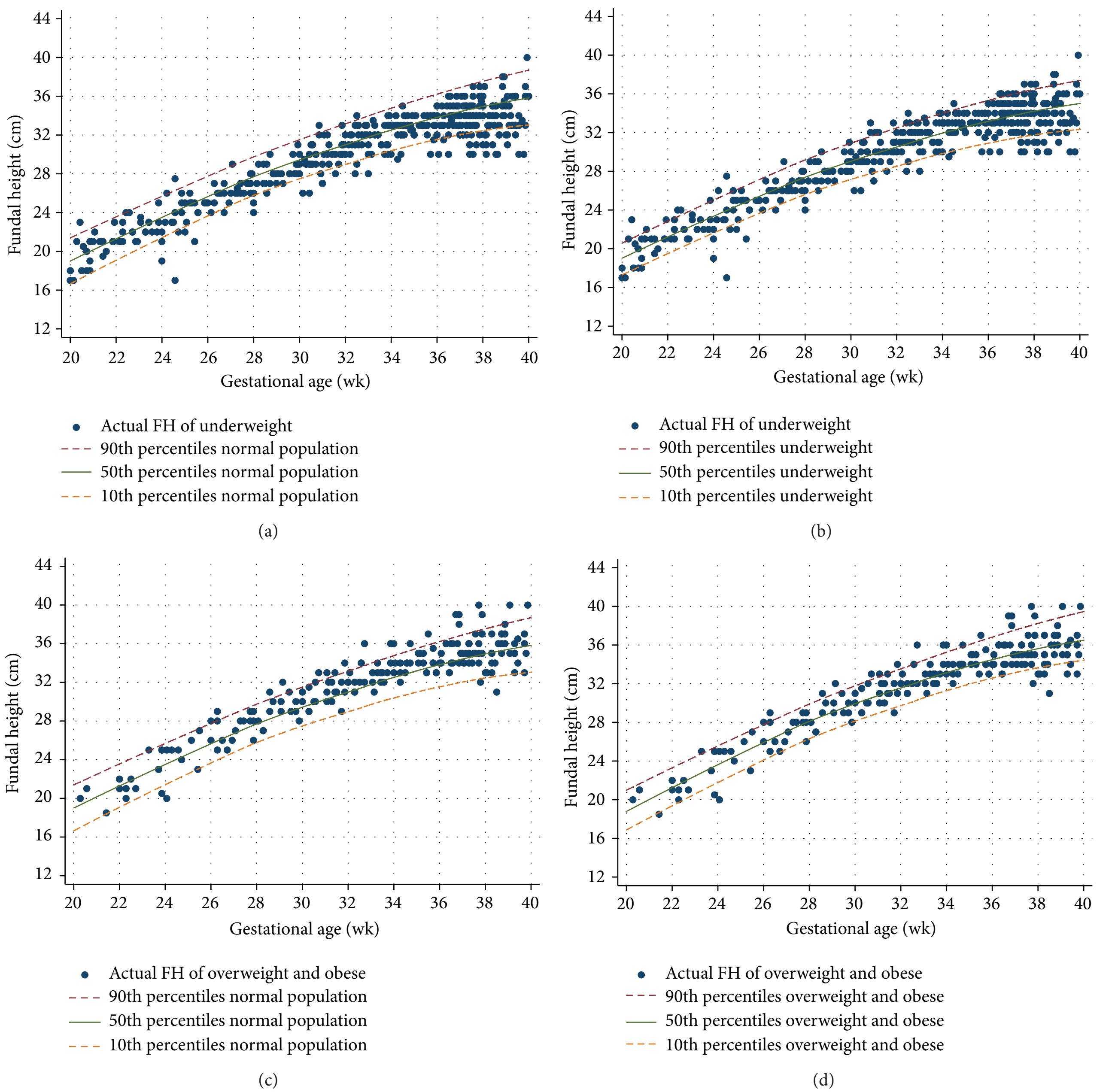

Figure 2: Fundal height (FH) of underweight and overweight and obese pregnant women as screened by different growth curves; (a) underweight pregnant women versus normal population curve; (b) underweight pregnant women versus underweight curve; (c) overweight and obese pregnant women versus normal curve; (d) overweight and obese pregnant women versus overweight and obese curve.

may use a FH growth curve that developed for normal population, while women with slim or obese body shapes should have their own FH growth curves for monitoring and screening abnormal intrauterine growth.

Application of FH growth curves specific for women body shape may reduce an over- or underinvestigation and/or -intervention. For example, in the underweight pregnant women, if a general FH growth curve was applied, FH below the 10th percentiles (size < date) would be detected in 15.4%, and FH above the 90th percentiles (size > date) in 1.2% (Figure 2(a)). On the contrary, if a specific FH growth curve for this group were applied the FH below the 10th percentiles would have been detected in 11.4%, and that above the 90th percentiles would have been 5.8% (Figure 2(b)). As a consequence, size < date was reduced 4.0% and size > date was increased 4.6%.

In the overweight and obese pregnant women, if a general FH growth curve was applied, FH above the 90th percentiles (size > date) would be detected in 11.1% and that below the 10th percentiles (size < date) in 3.0% (Figure 2(c)). If a specific FH growth curve for this group was applied the FH above the 90th percentiles would have been detected in 9.0%, and that below the 10th percentiles would have been 9.0% (Figure 2(d)), resulting in a 2.1% reduction of size > date and a 6.0% increase of size < date.

Body mass index categorization in the present study followed the WHO criteria [9], but the obese group was combined with the overweight group. This may limit the use of the developed curve in women with very high BMI (obese class II, BMI 35.0–39.9 kg/m^2 or obese class III, BMI ≥ 40.0 kg/m^2). Validation of the developed curve should be done before applying into routine clinical practice.

However, the developed FH growth curves for the underweight and overweight and obese pregnant women in this study was based on routine ANC practice of the four university affiliated hospitals in the upper northern part of Thailand. Generalization to other settings with different context, including the methods of FH measurement and the methods of GA assessments, may be limited.

Furthermore, the measurement of FH in normal practice is still considered "subjective" to intraobserver and interobserver errors. A standardized method should be reinforced, such as frequent validation or calibration, as we believe that simple FH measurement is of great value as a screening tool for routine antenatal care practice, especially in areas where health resources are limited.

5. Conclusions

Fundal height growth curves of the underweight (BMI < 18.5 kg/m^2) and overweight and obese (BMI ≥ 25.0 kg/m^2) women were different from the normal weight. In monitoring or screening for abnormal intrauterine growth in slim or obese women, FH growth curves specifically developed for such women should be applied. This may reduce an over- or underinvestigation and/or -intervention as a consequence of an inappropriate application of FH growth curve for normal weight women.

Conflict of Interests

The authors declare that they have no conflict of interests.

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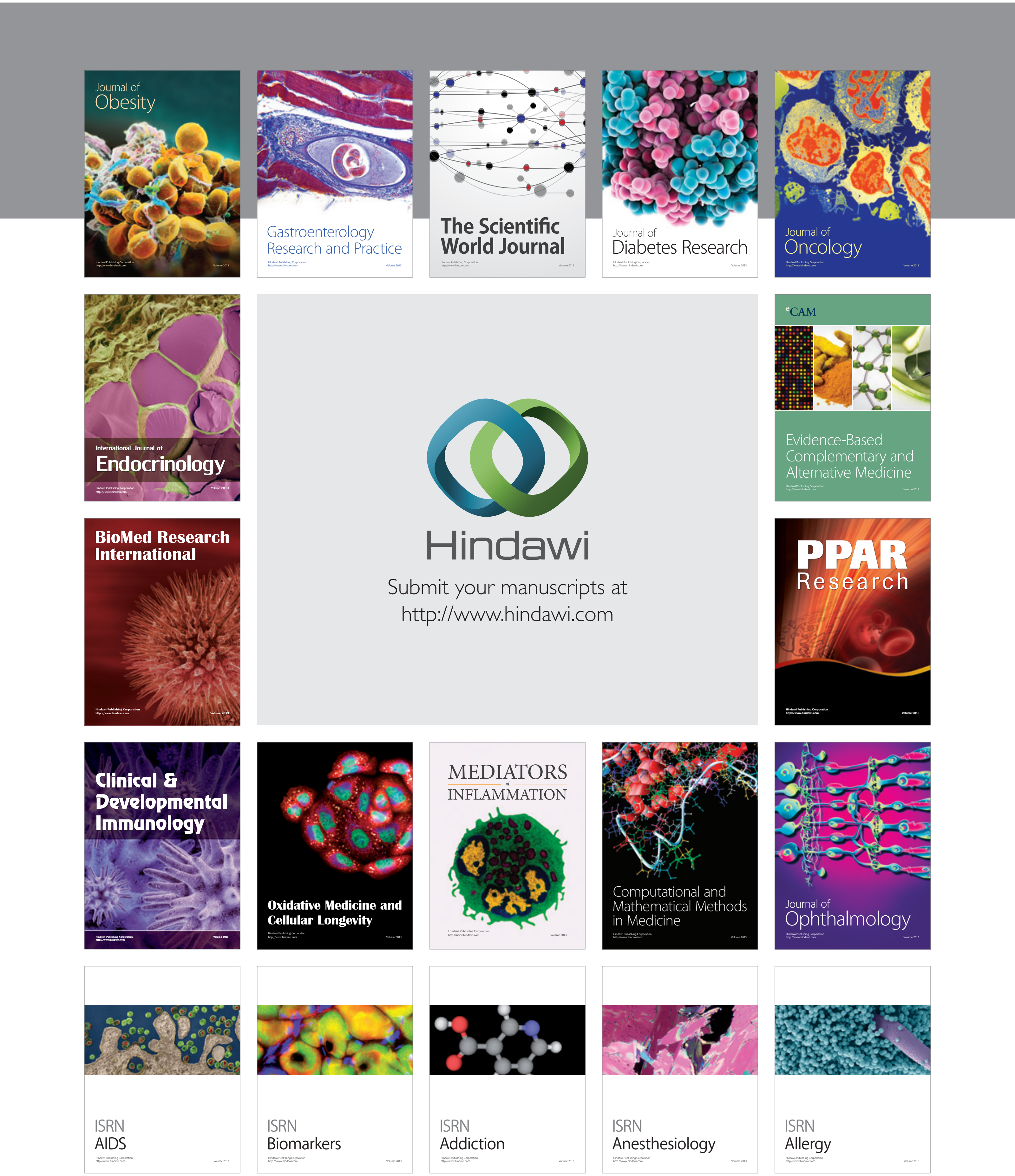
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Clinical Study

Fundal Height Growth Curve for Underweight and Overweight and Obese Pregnant Women in Thai Population

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Appendix D

Deeluea J, Sirichotiyakul S, Weerakiet S, Khunpradit S, Patumanond J. Fundal height growth curve patterns of pregnant women with term low birth weight infants. Risk Manag Healthc Policy. 2014;7:131-7.

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ORIGINAL RESEARCH

Fundal height growth curve patterns of pregnant women with term low birth weight infants

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Purpose: To investigate the patterns of fundal height (FH) growth curve in pregnant women with term low birth weight (LBW) infants compared with the standard FH growth curve for Thai women.

Subjects and methods: A retrospective study was conducted at the four governmental general hospitals in the northern part of Thailand between 2009 and 2011. All data were obtained from antenatal records and labor registry. Serial FH measurements in centimeters of 75 pregnant women with term LBW infants were plotted against the standard FH growth curve for Thai women throughout pregnancy.

Results: Six patterns of the FH growth curve were summarized: pattern I: FH below or around the tenth percentile throughout pregnancy (n=17, 22.7%); pattern II: FH below normal in early pregnancy, caught up with normal, then decelerated or stagnant (n=19, 25.3%); pattern III: FH normal in early pregnancy, then decelerated or stagnant (n=17, 22.7%); pattern IV: FH normal in early pregnancy, decelerated or stagnant, then caught up to normal (n=6, 8.0%); pattern V: FH normal throughout pregnancy except for the last visit (n=6, 8.0%); and pattern VI: FH normal throughout pregnancy (n=10, 13.3%).

Conclusion: Patterns I–V may be used to recognize women who are likely to deliver term LBW infants from early pregnancy, during pregnancy, and on the day of admission for labor. Ultrasound evaluation is still recommended in cases with known risk factors that might be undetectable by FH, or in cases where FH measurement may be inaccurate.

Keywords: fetal growth, pregnancy, antenatal care, screening

Introduction

Term low birth weight (LBW) infants (infants born weighing <2,500 g, between 37 and 42 completed weeks of gestation) are still prevalent and are among maternal and child health problems in developing countries, including Thailand. A survey in 138 countries of low and middle income in 2010 revealed that there were 10.6 million term LBW infants among 120.5 million live births (8.8%), most of them in Asia.[1] In Thailand the prevalence of LBW infants was 16.0%, among which 7.0% were preterm LBW and 9.0% were term LBW.[2]

The majority of term LBW infants are term small for gestational age (SGA) (infants with birth weight below the tenth percentile),[1] which increases the risk of perinatal morbidity and mortality, including perinatal asphyxia, meconium aspiration syndrome, hypothermia, hypoglycemia, and polycythemia,[3,4] and increased long-term morbidity, including poor mental and psychomotor development,[4,5] coronary heart disease, type 2 diabetes, and hypertension and stroke in adulthood.[6] Any screening process to detect

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pregnant women who are likely to give birth to term LBW infants may lessen these morbidities and mortalities.

Fundal height (FH) measurement is still a simple tool to monitor and screen term LBW infants, especially in settings where ultrasound is not available, as it is a proxy measure of fetal size or fetal weight.[7,8] Abnormality is suspected when FH does not match the FH obtained from normal pregnancy for the given gestational age (GA). It is also suspected when the pattern of FH growth reaches the lower boundary of the normal curve, such as –1 standard deviation (SD), –2 SDs, fifth percentile, tenth percentile, and a decelerated pattern or stable pattern that indicates that the fetus may be SGA or may have intrauterine growth restriction[8,9] leading to term LBW infants.

Previous studies showed that SGA or intrauterine growth restriction could be detected when applying the standard FH growth chart for every antenatal care (ANC) visit.[10–12] FH growth was dynamic and highly correlated to uterine contents, including the fetus, placenta, and amniotic fluid, but was mostly correlated to fetal size.[3] Serial FH measurements were therefore used to compare individual FH growth with the standard FH growth chart throughout pregnancy.

The studies on FH measurement in the past mostly focused on developing the "normal" FH growth curve appropriate for the geographical region.[13,14] No studies focused on the "pattern" of FH growth curve as an indication for abnormal fetal growth. The present study investigates the patterns of FH growth curve in pregnant women with term LBW infants compared with the standard FH growth curve for Thai women.[14]

Subjects and methods

Subjects

Retrospective data were collected of pregnant women with term LBW infants (born weighing <2,500 g, between 37 and 42 completed weeks of gestation) who attended ANC and delivered in the four governmental general hospitals in the northern part of Thailand between 2009 and 2011. Foreigners, minority groups, women who first visited ANC later than 20 weeks of gestation, unreliable GA, and twin pregnancy were excluded from the cohort inception.

Ascertainment of gestational age

GA was verified by: 1) first day of last menstrual period (LMP) in cases of regular menstruation, precise recall for LMP, and fundal size well correlated with GA, or LMP–GA was <1 week different from ultrasound; and 2) ultrasound was carried out in the first half of pregnancy in case of not recalled LMP, and FH uncorrelated to LMP–GA or >1 week different.

Fundal height measurement

Measurements of FH in the four settings were based on routine practice care recommended by the Division of Maternal and Child Health, the Ministry of Public Health, Thailand, and recorded in centimeters with nonelastic measurement tape from the upper border of the symphysis pubis to the top of the uterine fundus, or reversed direction. All measurements were taken by experienced nurses or clinicians with at least 2 years of ANC experience, in order to minimize measurement error and bias.

Standard fundal height growth curve for Thai women

The standard FH growth curve for women in the northern part of Thailand was developed from normal singleton pregnancy based on LMP and/or ultrasound dating reported and published earlier.[14]

In the process of screening, FH measurement was plotted on the standard FH growth curve displaying the 10th, 50th, and 90th percentile lines for every ANC visit throughout pregnancy.

Criteria for screening were as follows: 1) the fetal size and growth may be "normal" if FH was within the 10th and 90th percentile line and growth rate was a regular increment throughout pregnancy; and 2) the fetus may be smaller than GA or with slow intrauterine growth if FH was below the tenth percentile line or growth rate decelerated or stagnated, whether or not below the tenth percentile.

Data collection and data sources

Birth weight in grams, first day of LMP, ultrasound report, FH in centimeters, and general characteristics were extracted from ANC records, labor registry, and related medical records.

Statistical analysis

The FH measurements obtained from the four settings were standardized to correspond to the subjects used in the development of the standard FH growth curve for Thai women.

The characteristics of the index group (pregnant women with term LBW infants) and the standard group (normal singleton pregnancy used to develop the standard FH growth curve for Thai women) were presented as means, SDs, and frequencies and percentages. Comparisons across groups were done with independent *t*-tests or exact probability tests. A *P*-value <0.05 was considered statistically significant.

Serial FH measurements of pregnant women with term LBW infants were plotted against the standard FH growth curve for Thai women throughout pregnancy. The patterns of growth were summarized by three researchers in the team. The frequencies observed for each recognized pattern were reported.

Ethical approval

The study protocol was approved by the Research Ethics Committee, Faculty of Medicine, Chiang Mai University, Chiang Mai, Thailand, and the research ethics committees of the four hospitals.

Results

A total of 2,351 pregnant women attended ANC and delivered in the four settings during the study period. There were 75 pregnant women with term LBW infants who met the eligible criteria. The average birth weight of the index group was 2,350.8±130.5 g. Maternal height, prepregnancy weight, total weight gain, gestational weight gain within the recommendations of the Institute of Medicine,[15] and GA at birth of the index group were significantly lower than the standard group (Table 1). Settings, maternal age, prepregnancy body mass index (BMI), parity, GA at first antenatal visit, and infant's sex were similar (Table 1).

Patterns of FH growth curve for pregnant women with term LBW infants

Serial FH measurements of 75 pregnant women with term LBW infants against the standard FH growth curve for Thai women throughout pregnancy revealed six patterns of the FH growth curve. Examples of the six patterns are shown in Figure 1. The characteristics of the pregnant women for each pattern are shown in Table 2.

- Pattern I (n=17, 22.7%): the FHs were around or below the tenth percentile throughout pregnancy (Figure 1A).
- Pattern II (n=19, 25.3%): the FHs were around or below the tenth percentile in early GA and resumed to a normal level afterward, then became decelerated or stagnant until before delivery, at which time they were either below the tenth percentile (n=16, 21.3%) or above the tenth percentile (n=3, 4.0%) (Figure 1B).

Table 1 Characteristics of study subjects

Characteristics	Pregnant women with term LBW infants (index group)[a] (n=75; 530 visits)	Normal singleton pregnancies (standard group)[b] (n=1,038; 7,523 visits)	*P*-value
Settings (n, %)			0.202
Secondary care hospitals	56 (74.7)	696 (67.0)	
Tertiary care hospitals	19 (25.3)	342 (33.0)	
Maternal age (year)*	25.0±7.6	25.6±6.2	0.456
Maternal height (cm)*	153.4±5.3	156.1±5.6	<0.001
Prepregnancy weight (kg)*	49.3±7.4	52.6±9.8	<0.001
Prepregnancy BMI (kg/m²)*	21.0±2.9	21.6±3.8	0.074
Total weight gain (kg)*	11.0±4.5	13.5±4.7	<0.001
Gestational weight gain (n, %)[c]			<0.001
Less than recommended	40 (53.3)	303 (29.2)	
Within recommended	28 (37.3)	430 (41.4)	
More than recommended	7 (9.4)	305 (29.4)	
Parity (n, %)			0.403
Nulliparous	42 (56.0)	523 (50.4)	
Multiparous	33 (44.0)	515 (49.6)	
GA at first antenatal visit (week)*	12.7±5.2	13.0±5.0	0.586
GA at birth (week)*	38.4±0.9	39.2±1.1	<0.001
Infant's sex (n, %)			0.187
Female	41 (54.7)	479 (46.2)	
Male	34 (45.3)	559 (53.8)	
Birth weight (g)*	2,350.8±130.5	3,120.3±325.0	<0.001

Notes: *The values are expressed as mean ± SD. [a]Term LBW infants: infants born weighing <2,500 g between 37 and 42 completed weeks of gestation; [b]developed standard fundal height growth curve for Thai women;[14] [c]recommendations by the Institute of Medicine: underweight prepregnancy BMI (<18.5 kg/m²) =12.5–18 kg; normal weight (18.5–24.9 kg/m²) =11.5–16 kg; overweight (25.0–29.9 kg/m²) =7–11.5 kg; obese (≥30.0 kg/m²) =5–9 kg.[15] Copyright © 2013 Jirawan Deeluea et al. Deeluea J, Sirichotiyakul S, Weerakiet S, Buntha R, Tawichasri C, Patumanond J. Fundal height growth curve for Thai women. *ISRN Obstet Gynecol*. 2013;2013:463598.[14]
Abbreviations: BMI, body mass index; GA, gestational age; LBW, low birth weight; SD, standard deviation.

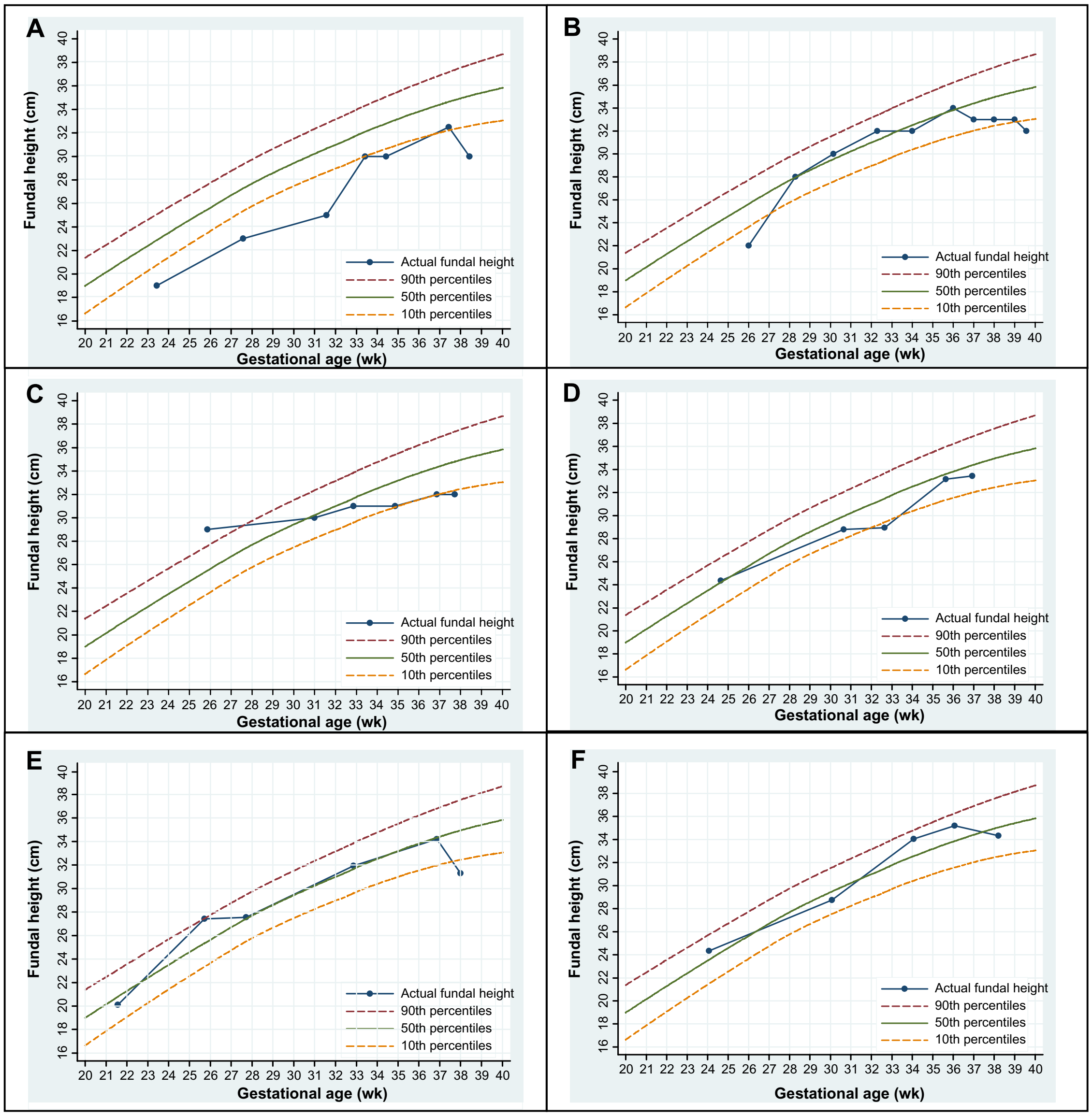

Figure 1 Example of FH growth curve patterns of six selected pregnant women with term LBW infants against standard FH growth curve for Thai women.
Notes: (**A**) Pattern I: FH below or around the tenth percentile throughout pregnancy. (**B**) Pattern II: FH below normal in early pregnancy, caught up with normal, then decelerated or stagnant. (**C**) Pattern III: FH normal in early pregnancy, then decelerated or stagnant. (**D**) Pattern IV: FH normal in early pregnancy, decelerated or stagnant, then caught up to normal. (**E**) Pattern V: FH normal throughout pregnancy except for the last visit. (**F**) Pattern VI: FH normal throughout pregnancy.
Abbreviations: FH, fundal height; LBW, low birth weight; wk, week.

- Pattern III (n=17, 22.7%): the FHs were between the 50th and 90th percentile in early GA, then became decelerated or stagnant until before delivery, at which time they were either below the tenth percentile (n=15, 20.0%) or above the tenth percentile (n=2, 2.7%) (Figure 1C).
- Pattern IV (n=6, 8.0%): the FHs were between the 50th and 90th percentile in early GA, then became decelerated or stagnant until they were either below the tenth percentile (n=3, 4.0%) or above the tenth percentile (n=3, 4.0%), but resumed to a normal level afterward (Figure 1D).
- Pattern V (n=6, 8.0%): the FHs were between the 10th and 90th percentile throughout pregnancy, except for a visit before or at delivery, when FH was below the 10th percentile (Figure 1E).
- Pattern VI (n=10, 13.3%): the FHs were between the 10th and 90th percentile lines throughout pregnancy (Figure 1F).

Discussion

The standard FH growth curve for Thai women with 10th, 50th, and 90th percentile lines was supposed to be a simple tool to monitor fetal growth and to screen for suspected abnormal intrauterine growth. Small fetuses or fetuses with a slow intrauterine growth rate should be recognized by a

Table 2 Characteristics of pregnant women for six patterns of fundal height growth curve (n=75)

Characteristics	Pattern I (n=17)	Pattern II (n=19)	Pattern III (n=17)	Pattern IV (n=6)	Pattern V (n=6)	Pattern VI (n=10)
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Age (year)	20.1±4.6	27.2±7.8	26.1±6.7	23.8±10.5	28.0±8.4	26.0±8.3
Height (cm)	153.9±5.7	154.3±3.6	154.5±6.3	153.1±3.0	153.4±2.9	149.3±6.5
Prepregnancy weight (kg)	46.3±7.1	47.6±5.3	54.6±9.0	49.7±5.7	49.3±8.2	48.7±6.0
Prepregnancy BMI (kg/m^2)	19.5±2.9	20.0±2.1	22.9±3.2	21.2±2.1	20.9±2.9	21.9±2.5
Total weight gain (kg)	8.9±3.2	10.7±2.9	10.6±5.0	12.8±7.2	11.4±5.1	14.6±4.4
Low gestational WG[a] (n, %)	13 (76.5)	12 (63.2)	7 (41.2)	3 (50.0)	3 (50.0)	2 (20.0)
Nulliparous (n, %)	12 (70.6)	7 (36.8)	10 (58.8)	3 (50.0)	5 (83.3)	5 (50.0)
GA at birth (wk)	38.2±0.7	38.3±0.8	38.7±0.9	38.8±1.2	38.0±0.9	38.3±0.9
Female infant (n, %)	9 (52.9)	11 (57.9)	9 (52.9)	3 (50.0)	4 (66.7)	5 (50.0)
Birth weight (g)	2,284.4±156.5	2,386.0±112.6	2,376.2±108.3	2,338.3±156.9	2,374.2±121.4	2,347.0±125.3
Medical complications (n, %)						
Chronic hypertension	N/A	N/A	N/A	N/A	N/A	1 (10.0)
Pregestational DM	N/A	N/A	1 (5.9)	N/A	N/A	N/A
Thalassemia disease	1 (5.9)	1 (5.3)	N/A	N/A	N/A	N/A
Asthma	N/A	1 (5.3)	N/A	N/A	N/A	N/A
Obstetric complications (n, %)						
Hyperemesis gravidarum	N/A	N/A	1 (5.9)	N/A	N/A	N/A
Gestational hypertension	N/A	N/A	N/A	N/A	N/A	1 (10.0)
Anemia during pregnancy	2 (11.8)	N/A	1 (5.9)	1 (16.7)	N/A	N/A
Oligohydramnios	1 (5.9)	1 (5.3)	1 (5.9)	N/A	N/A	N/A
IUGR	7 (41.2)	1 (5.3)	2 (11.8)	N/A	N/A	1 (10.0)

Note: [a]Gestational weight gain was lower than the recommendations by the Institute of Medicine.[15]
Abbreviations: BMI, body mass index; DM, diabetes mellitus; GA, gestational age; IUGR, intrauterine growth restriction; SD, standard deviation; WG, weight gain; wk, week.

deviation from FH growth of the norms, as shown by both the pattern of growth and the timing at which the abnormality was detected.

The findings suggested six different patterns of FH growth curve observed in pregnant women with term LBW infants. Each pattern may have different or similar explanations as follows.

Pattern I

The fetus is likely to be small throughout pregnancy. This may reflect genetic and constitutional influences such as mothers with a small body frame and mothers who were SGA or who had delivered LBW infants, resulting in a "constitutionally" or "natural" small infant with otherwise normal growth.[16,17] It may also reflect risk factors for term LBW infants from the beginning of pregnancy, such as nulliparous, teenage, low prepregnancy weight, low BMI, or thalassemia disease, combined with low gestational weight gain, anemia during pregnancy, or an abnormal placenta that led to insufficient nutrients and oxygen supply to the fetus and resulting in intrauterine growth restriction.[17–19] Pregnant women in this pattern had lower age, prepregnancy weight, prepregnancy BMI, and gestational weight gain than those in patterns II–VI (Table 2).

Pattern II

The fetus is likely to be small in early pregnancy, which may be due to risk factors for term LBW infants such as a small mother, nulliparous, low BMI, maternal malnutrition, or diseases leading to hypoxemia such as asthma or thalassemia disease. Nutrient and oxygen supply to the fetus may be improved from better nutrition[20] or underlying controllable conditions,[9] resulting in resumption to normal levels. Nutrients, especially glucose, may be insufficient in the last trimester,[3] and low gestational weight gain, psychosocial stress, or abnormal function of the placenta[17,21] may lead to decelerated growth observed in late pregnancy.

Pattern III

The fetus is likely to be normal in early pregnancy. The growth rate may be decelerated from late causes for term LBW infants such as vascular diseases, anemia during pregnancy, partial placental separation, intervillous or spiral artery thrombosis, or placental infarcts leading to uteroplacental insufficiency or hypoxemia,[19,22] combined with poor maternal nutrition, especially in the third trimester, or low gestational weight gain leading to fetal undernutrition.[17,18]

Pattern IV

The fetus is likely to be normal in early pregnancy. Late causes for term LBW infants decelerated the growth but are corrected or received intervention, causing resumption of the growth rate, but are insufficient to catch up with the norms. Other causes for FH larger than the actual size of the fetus in late pregnancy may be observed where there is excessive volume of amniotic fluid, abnormal fetal position, or abnormal pelvis.[23]

Pattern V

The fetus is likely to be normal throughout pregnancy. Uteroplacental insufficiency may be encountered near term.[24] As fetal weight gain beyond 34 weeks should be 30–35 g/day or 210–245 g/week,[3] the rate below this may result in term BW <2,500 g.

Pattern VI

As FH is only a surrogate measure for fetal size, it does not reflect just the fetal size but may be influenced by the amount of amniotic fluid, fetal position, body shape, and types of pelvis.[23] Furthermore, a standard FH growth curve derived from all pregnant women may not be appropriate for women with low or high BMI,[25] causing false classification.

From the six patterns proposed, there were four patterns (patterns I–IV) that may be used as guidelines to screen for term LBW infants from early pregnancy (78.7%), and one pattern (pattern V) that may be used to detect the condition only before or at delivery (8.0%). The other pattern (pattern VI) failed to detect such condition (13.3%).

In pattern VI, where the FH growth curve did not indicate any abnormalities, other factors contributive to a falsely large FH should be explored, such as women with BMI >35 kg/m^2, which may lead to inaccurate measurement, large fibroids, or polyhydramnios. In these cases, other investigations may be required, such as serial ultrasound measurements, uterine artery Doppler, or umbilical artery Doppler.[9,26] Furthermore, applying an FH growth curve that is more specific to individuals may be more appropriate in underweight or overweight and obese pregnant women.[25]

The patterns of the FH growth curve in pregnant women with term LBW infants plotted against the standard FH growth curve for Thai women may reflect the size and growth of the fetus at different stages of pregnancy. It might be used as a guideline or a simple tool to monitor and screen for term LBW infants, from early pregnancy. Detected cases need intervention to reduce complications that may arise from term LBW infants.

Although the present study may be the first to report the patterns of the FH growth curve in pregnant women with term LBW infants, it was conducted only in women who attended ANC in the four governmental general hospitals in the northern part of Thailand and with a limited number of subjects, as most of the pregnant women with term LBW infants were excluded due to late ANC. The effectiveness and benefit of using this approach in the screening for term LBW infants should be verified by future studies before it is adopted into routine clinical practice.

Conclusion

The patterns of FH growth curves observed among pregnant women with term LBW infants may be used to identify women who are likely to deliver term LBW infants from early pregnancy, during pregnancy, and on the day of admission for labor. Such screening may detect future term LBW infants in 80%. An intervention in screening-detected cases may reduce the incidence of, or lessen the complications in, fetuses <2,500 g. Ultrasound evaluation is still recommended in cases with risk factors that cannot be detected by FH measurements, or in cases where FH measurement may be inaccurate.

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Disclosure

The authors declare no conflicts of interest.

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