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Reference ranges for fetal tricuspid and mitral annular plane systolic excursions

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Abstract

Objectives: Echocardiography is the standard tool for assessing fetal cardiac function. Tricuspid annular plane systolic excursion (TAPSE) and mitral annular plane systolic excursion (MAPSE) are simple, reliable indicators of systolic function. Many studies have established reference ranges in adult and pediatric populations; however, data remain limited in fetuses, especially in Southeast Asia. The aim of the study was to establish normal reference ranges for TAPSE and MAPSE in fetuses born between 18 + 0 and 37 + 6 weeks' gestation in a Southeast Asian population.

Methods: This prospective, cross-sectional study was conducted between January 2024 and February 2025. Data from 280 singleton pregnancies with normal fetal growth and no maternal comorbidities were included in the study. TAPSE and MAPSE were measured using M-mode imaging in a four-chamber view. Percentile reference values were determined using quantile regression models, with gestational age (GA) and estimated fetal weight (EFW) as predictors. The intraclass correlation coefficient (ICC) was used to assess intra- and interobserver reliability.

Results: TAPSE and MAPSE were significantly and positively correlated with GA and EFW. Mean TAPSE ranged from 3.76 to 9.08 mm (GA) and 3.42 to 9.30 mm (EFW), while MAPSE ranged from 3.10 to 6.34 mm (GA) and 2.71 to 6.60 mm (EFW). The TAPSE values consistently exceeded the MAPSE values across all GAs. The inter- and intra-observer ICCs were high (TAPSE, 0.94/0.91; MAPSE, 0.91/0.88).

Conclusions: This study established the first normal TAPSE and MAPSE reference ranges for a Southeast Asian population and provided reliable tools for fetal cardiac assessment.

Keywords: tricuspid annular plane systolic excursion; mitral annular plane systolic excursion; fetal cardiac function; fetal echocardiography; M-mode

Introduction

Echocardiography is the standard modality essential for evaluating fetal cardiac function. Evaluation of fetal cardiac function is particularly critical in cases of congenital fetal cardiac anomalies, fetal tumors [1], fetal anemia [2], fetal growth restriction (FGR) [3], twin-to-twin transfusion syndrome (TTTS) [4, 5], and placental tumors [1]. Various sonographic techniques are used to assess systolic, diastolic, and global cardiac functions. For instance, the E/A ratio is used to evaluate diastolic function, while parameters such as shortening fraction, ejection fraction, tricuspid annular plane systolic excursion (TAPSE), and mitral annular plane systolic excursion (MAPSE) are utilized for systolic function. The myocardial performance index provides an assessment of global cardiac function. However, no main method for functional assessment. This study will focus on measuring fetal systolic function [6, 7].

Fetal systolic function can be quantified using parameters including shortening fraction, ejection fraction, TAPSE, and MAPSE [6]. Although shortening and ejection fractions provide valuable data, they typically show changes in the late stages of fetal cardiac dysfunction. Moreover, the complexity of their calculation may be limited in specific situations. Conversely, TAPSE and MAPSE reflect the maximum vertical displacement of the lateral leaflet of the atrioventricular valve using M-mode, and their values can detect changes as early as the initial stages of cardiac dysfunction. These methods are simple and easy to perform and do not require advanced ultrasonography techniques. Moreover, TAPSE and MAPSE be measured using standard ultrasound equipment and are practical for routine clinical applications.

While the normal reference ranges for TAPSE and MAPSE have been extensively studied in adult [8–10] and

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pediatric [11–14] populations, data regarding fetal reference ranges remain limited, particularly among Southeast Asian populations. As such, this study aimed to establish normal reference ranges for TAPSE and MAPSE in fetuses at 18 + 0 to 37 + 6 weeks' gestation.

Materials and methods

Study population

This prospective cross-sectional study was conducted from January 2024 to February 2025 at Srinagarind Hospital, Faculty of Medicine, Khon Kaen University, Thailand. The inclusion criteria included women ≥ 18 years of age with a singleton pregnancy, an accurately determined gestational age (GA) based on crown–rump length measurement during the first trimester, normally grown fetuses, no maternal underlying diseases, and GA between 18 + 0 and 37 + 6 weeks. The exclusion criteria included fetuses with structural anomalies, aneuploidy, or intrauterine growth restriction by Lees et al. [15]. Withdrawal criteria included the identification of fetal cardiac anomalies or other structural abnormalities at birth. Informed consent was obtained from all participants before enrollment in the study. The study was approved by the Khon Kaen University Ethics Committee for Human Research, and adhered to the Declaration of Helsinki and the International Council for Harmonization Good Clinical Practice Guidelines (reference number HE661527).

To evaluate the characteristics of the study population, data regarding maternal age, ethnicity, number of pregnancies, parity, gestational age, pre-pregnancy weight, and height, were collected. All study participants were followed-up postpartum

to confirm the absence of structural or cardiac abnormalities in the fetus through routine physical examination. Inter- and intra-observer variabilities were also assessed. This process was blinded to the two sonographers (J.K. and R.K.) who independently evaluated 10 random cases. The intraclass correlation coefficient (ICC) was calculated with corresponding 95 % confidence interval (CI), with an acceptable CI width of 0.15 mm. Intra-observer variability (J.K.) was assessed by performing two measurements 15 min apart in 16 participants. The intraclass correlation coefficient (ICC) was calculated with corresponding 95 % confidence interval (CI), with an acceptable CI width of 0.10 mm.

Sonography

Examinations were performed using an ultrasound device (Voluson E10 or S8, GE Healthcare Ultrasound, Milwaukee, WI, USA) equipped with an XDclear wide-band convex probe C1-6-D, with a maximum bandwidth of 2–5 MHz. GA was determined based on the last menstrual period and was confirmed using ultrasonography in the first-trimester. All participants underwent fetal anomaly scans by J.K. according to the International Society of Ultrasound in Obstetrics and Gynecology Practice Guidelines for routine mid-trimester fetal ultrasound [16]. Fetal biometry was performed, and estimated fetal weight (EFW) was calculated using the equation described by Hadlock et al. [17].

Positional measurements of TAPSE (Figure 1A) and MAPSE (Figure 1B) were obtained using a four-chamber view with the fetal heart positioned at 12 or 6 o'clock. The image was adjusted and conventional M-mode was used. A cursor was placed through the lateral leaflets of the tricuspid and

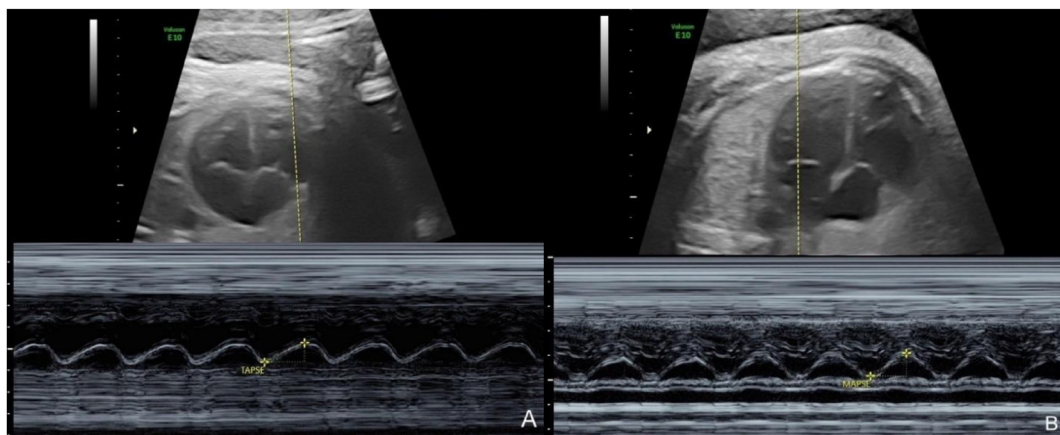


Figure 1: Ultrasound images of the apical four-chamber view of the fetal cardiac demonstrated longitudinal atrioventricular valve motion measurement with the M-mode. (A) Tricuspid annular plane systolic excursion (TAPSE), (B) mitral valve annular plane systolic excursion (MAPSE). Longitudinal displacement measurement is demonstrated at the bottom of the image.

mitral valves, maintaining an insonation angle of $<15^\circ$ relative to the interventricular septum during maternal breath-holding and fetal rest. The maximum longitudinal displacement of atrioventricular valve motion was measured. Each evaluation was performed 3 times and the mean value was calculated and used in the analysis [18].

Statistical analysis

Scatter plots of individual MAPSE and TAPSE values vs. GA and EFW were examined. TAPSE and MAPSE exhibited nonlinear associations with GA and EFW, with increasing variability observed as GA and EFW advanced. Logarithmic transformation was applied to the GA and EFW to enhance linearity and improve the model fit. Simultaneous quantile regression was performed to estimate the 1st, 2.5th, 5th, 10th, 25th, 50th, 75th, 90th, 97.5th, and 99th percentiles of MAPSE and TAPSE as functions of GA and EFW. All statistical analyses were performed using Stata Release 18.0 (StataCorp LLC, College Station, TX, USA).

The required sample size for each GA group was determined using an equation to estimate the population mean. The calculation was based on the following parameters: a Z-score of 1.96 for the desired confidence level; a standard deviation of 0.65 cm; and a margin of error of 0.35 cm. Applying these values, the estimated sample size per GA group was 14 pregnancies, with a total of 280 participants.

Results

Data from 280 pregnant women who fulfilled the inclusion and exclusion criteria for establishing a normal reference range were included. The demographic characteristics of the study population and perinatal outcomes are summarized in Table 1. The mean maternal age was 33.0 years, and the mean pre-pregnancy body mass index was 23.8 kg/m^2 . Most participants were pregnant Thai women. The median GA at delivery was 38 weeks, with a mean birth weight of 3,081 g. A total of 135 and 145 pregnant women underwent vaginal and cesarean deliveries, respectively, with mean Apgar scores of 8 and 9 at 1 and 5 min. Normal reference ranges for TAPSE based on GA and EFW, respectively, are summarized in Tables 2 and 3. The mean TAPSE across GA ranged from 3.76 to 9.08 mm, while the mean TAPSE across EFW ranged from 3.42 to 9.30 mm. Scatterplots for TAPSE vs. GA and EFW, illustrating an increasing trend with gestational age, are presented in Figures 2 and 3. Normal reference ranges for the MAPSE based on GA and EFW are presented in Tables 4 and 5. The mean

Table 1: Demographics of the study populations.

Characteristic	Value
Maternal age, years	33.0 ± 4.8 (mean $\pm$ SD)
Body mass index, kg/m^2	23.8 ± 5.0 (mean $\pm$ SD)
Gestational age at birth, weeks	38 (38,39) (median, IQR)
Type of delivery	
–Vaginal	135 (48 %)
–Cesarean	145 (52 %)
Birth weight, grams	$3,081 \pm 439$ (mean $\pm$ SD)
Apgar 1 min	8 (8,8) (median, IQR)
Apgar 5 min	9 (9,9) (median, IQR)
Nulliparity	140 (50 %)
Multiparity	140 (50 %)
Ethnicity	
–Thai	276 (99 %)
–Laotian	4 (1 %)

SD, standard deviation; IQR, interquartile range.

MAPSE across GA ranged from 3.10 to 6.34 mm, while the mean MAPSE across EFW varied from 2.71 to 6.60 mm. Scatterplots for MAPSE vs. GA and EFW, demonstrating an increase with GA, are presented in Figures 4 and 5. Both TAPSE and MAPSE exhibited significant positive correlations with GA and EFW. The optimal model for predicting these values was a logarithmic transformation that provided the best fit. Notably, the mean TAPSE values consistently exceeded the MAPSE values at all GAs.

The ICC between the two sonographers (i.e., J.K. and R.K.) for TAPSE was 0.94 (95 % CI 0.77–0.99) and 0.91 (95 % CI 0.65–0.98) for MAPSE. The ICC for two repeat measurements by J.K. was 0.91 (95 % CI, 0.74–0.97) for TAPSE and 0.88 (95 % CI, 0.65–0.96) for MAPSE. The Bland-Altman plots demonstrate the mean difference of repeated measurement by the same examiner (intra-observer) for TAPSE and MAPSE, which are $0.12 \pm 0.65 \text{ mm}$ and $-0.12 \pm 0.53 \text{ mm}$, respectively Figures 6 and 7. The mean difference between two examiners (inter-observer) for TAPSE and MAPSE were $-0.03 \pm 0.60 \text{ mm}$ and $0.28 \pm 0.70 \text{ mm}$, respectively, Figures 8 and 9.

Discussion

Several studies have established normal reference values for fetal TAPSE and MAPSE in various populations, including Israel, China, Australia, and Brazil [18–21]. The reference values at corresponding gestational ages vary across these studies, suggesting that population-specific differences may influence these parameters. Currently, no studies have investigated these parameters in Southeast Asian populations. This study established normal reference ranges for

Table 2: Percentile for tricuspid annular plane systolic excursion (TAPSE) (millimeters) by gestation age (GA).

GA, weeks	n	Percentile										
		1	2.5	5	10	25	50	75	90	95	97.5	99
18	14	2.29	2.36	2.60	3.19	3.58	3.76	4.29	5.44	5.37	5.85	5.81
19	14	2.55	2.67	2.92	3.48	3.89	4.16	4.72	5.85	5.84	6.30	6.32
20	14	2.80	2.96	3.22	3.75	4.19	4.54	5.13	6.23	6.28	6.73	6.81
21	14	3.04	3.24	3.51	4.01	4.47	4.90	5.52	6.60	6.71	7.13	7.27
22	14	3.27	3.51	3.78	4.26	4.74	5.24	5.90	6.95	7.12	7.52	7.71
23	14	3.49	3.76	4.04	4.49	5.00	5.57	6.25	7.28	7.50	7.89	8.14
24	14	3.70	4.01	4.29	4.72	5.25	5.89	6.60	7.60	7.87	8.25	8.54
25	14	3.89	4.24	4.53	4.93	5.48	6.19	6.92	7.91	8.23	8.59	8.93
26	14	4.09	4.47	4.76	5.14	5.71	6.48	7.24	8.20	8.57	8.92	9.30
27	14	4.27	4.68	4.98	5.34	5.93	6.75	7.54	8.49	8.90	9.23	9.66
28	14	4.45	4.89	5.19	5.53	6.14	7.02	7.83	8.76	9.22	9.53	10.00
29	14	4.62	5.09	5.40	5.72	6.34	7.28	8.11	9.02	9.52	9.83	10.34
30	14	4.79	5.28	5.60	5.90	6.54	7.53	8.39	9.28	9.82	10.11	10.66
31	14	4.95	5.47	5.79	6.07	6.73	7.77	8.65	9.53	10.10	10.38	10.97
32	14	5.10	5.65	5.97	6.24	6.91	8.01	8.90	9.76	10.38	10.65	11.27
33	14	5.25	5.83	6.16	6.41	7.09	8.24	9.15	10.00	10.65	10.90	11.57
34	14	5.40	6.00	6.33	6.56	7.26	8.46	9.39	10.22	10.91	11.15	11.85
35	14	5.54	6.17	6.50	6.72	7.43	8.70	9.62	10.44	11.16	11.40	12.12
36	14	5.68	6.33	6.66	6.87	7.59	8.88	9.85	10.65	11.41	11.63	12.39
37	14	5.81	6.48	6.83	7.01	7.75	9.08	10.07	10.86	11.65	11.86	12.65

Table 3: Percentile of tricuspid annular plane systolic excursion (TAPSE) (millimeters) by estimated fetal weight (EFW).

EFW, grams	n	Percentile										
		1	2.5	5	10	25	50	75	90	95	97.5	99
200–399	46	2.17	2.28	2.29	2.79	3.12	3.42	3.93	4.49	4.92	5.37	5.38
400–599	34	3.02	3.30	3.36	3.83	4.28	4.83	5.45	6.12	6.55	7.03	7.10
600–799	26	3.51	3.90	3.99	4.43	4.96	5.65	6.34	7.08	7.51	8.00	8.11
800–999	20	3.87	4.32	4.44	4.87	5.44	6.24	6.97	7.75	8.19	8.69	8.83
1,000–1,199	15	4.14	4.65	4.78	5.20	5.81	6.69	7.46	8.28	8.72	9.22	9.38
1,200–1,399	18	4.36	4.92	5.06	5.48	6.12	7.06	7.86	8.71	9.15	9.66	9.83
1,400–1,599	22	4.55	5.15	5.30	5.71	6.38	7.38	8.20	9.07	9.51	10.03	10.22
1,600–1,799	12	4.71	5.34	5.51	5.91	6.60	7.65	8.49	9.38	9.83	10.35	10.55
1,800–1,999	9	4.86	5.52	5.69	6.08	6.80	7.89	8.75	9.66	10.10	10.63	10.84
2,000–2,199	12	4.99	5.67	5.85	6.24	6.98	8.10	8.98	9.91	10.35	10.88	11.11
2,200–2,399	18	5.10	5.81	6.00	6.38	7.13	8.30	9.19	10.13	10.58	11.11	11.34
2,400–2,599	14	5.21	5.94	6.14	6.52	7.28	8.47	9.38	10.34	10.78	11.32	11.56
2,600–2,799	13	5.31	6.06	6.26	6.64	7.41	8.64	9.55	10.53	10.97	11.51	11.76
2,800–2,999	9	5.40	6.17	6.37	6.75	7.54	8.79	9.71	10.70	11.15	11.69	11.94
3,000–3,199	8	5.48	6.27	6.48	6.85	7.65	8.93	9.86	10.86	11.31	11.85	12.11
3,200–3,399	2	5.56	6.37	6.58	6.95	7.76	9.06	10.01	11.01	11.46	12.01	12.27
3,400–3,599	2	5.64	6.45	6.67	7.04	7.86	9.18	10.14	11.16	11.61	12.15	12.43
≥3,600	0	5.71	6.54	6.76	7.12	7.96	9.30	10.26	11.29	11.74	12.29	12.57

TAPSE and MAPSE in fetuses between 18 + 0 and 37 + 6 weeks' GA. TAPSE and MAPSE progressively increased with advancing GA and EFW, exhibiting a logarithmic correlation. Our results are similar to those reported by Herling et al. [22].

However, previous studies reported a linear correlation, which differed slightly from our findings. These differences may be attributed to our study's earlier GA range [19–21] and larger sample size compared with previous studies [18, 20]. Several studies evaluating TAPSE in healthy pediatric

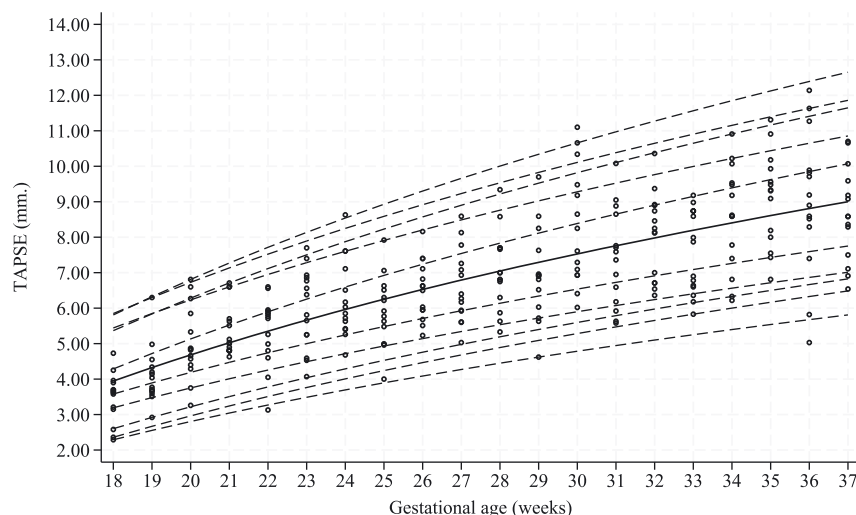


Figure 2: Scatterplots of tricuspid annular plane systolic excursion (TAPSE) based on gestational age (GA) in the study population. Estimated 1st, 2.5th, 5th, 10th, 25th, 50th, 50th, 75th, 90th, 95th, 97.5th, and 99th percentiles curves are shown.

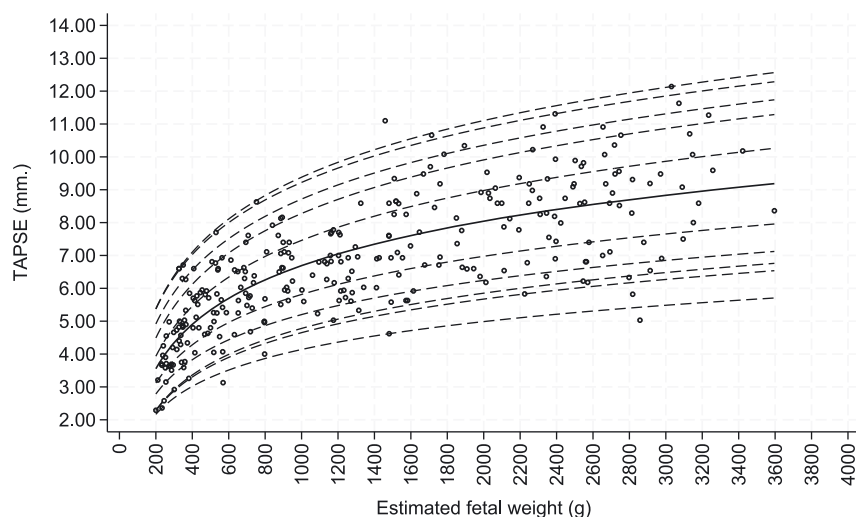


Figure 3: Scatterplots of tricuspid annular plane systolic excursion (TAPSE) based on estimated fetal weight (EFW) in the study population. Estimated 1st, 2.5th, 5th, 10th, 25th, 50th, 50th, 75th, 90th, 95th, 97.5th, and 99th percentiles curves are shown.

populations have demonstrated a positive correlation between TAPSE values and increasing weight and body surface area [11–13], consistent with our findings of a positive correlation between TAPSE and MAPSE with EFW.

TAPSE consistently exceeded MAPSE throughout gestation, reflecting a higher fetal cardiac output from the right ventricle than that from the left ventricle. This suggests that fetal right ventricular compliance was greater than left ventricular compliance [23]. These findings are consistent with those from previous studies [18–22]. Using TAPSE and MAPSE based solely on GA may not be appropriate, particularly in conditions such as FGR, in which fetal weight does not correspond to GA. EFW-based assessment provides a more accurate evaluation of fetal cardiac function. Our study provides percentile tables for TAPSE and MAPSE correlated with EFW, which may be clinically useful for fetuses diagnosed with these specific conditions.

TAPSE and MAPSE are widely used in various clinical contexts to evaluate fetal cardiac function. Several studies

have assessed TAPSE and MAPSE under specific pathological conditions, including fetal anemia. Pre-intrauterine blood transfusion (IUT) measurements revealed annular plane systolic excursion values above the normal reference range, significantly decreasing post-IUT [2]. Similarly, a study involving 11 cases of placental tumors found that 8 of 11 fetuses exhibited TAPSE values above the normal reference range [1]. These findings suggest that the annular plane systolic excursion values in high cardiac output states tend to exceed the normal reference range.

Conversely, studies focusing on fetal heart failure have demonstrated significantly lower TAPSE, MAPSE, and myocardial performance index values than those of normal fetuses, often falling >2 standard deviations below the mean [24]. Furthermore, in fetuses with FGR, TAPSE values are significantly lower than those in normal fetuses [3]. Additional research investigating maternal preeclampsia has revealed a decrease in fetal TAPSE [25]. In TTTS, donor and recipient twins exhibit TAPSE values that are lower than

Table 4: Percentile of mitral annular plane systolic excursion (MAPSE) (millimeters) by gestational age (GA).

GA, weeks	n	Percentile										
		1	2.5	5	10	25	50	75	90	95	97.5	99
18	14	1.34	1.98	1.95	2.16	2.54	3.10	3.38	3.87	4.09	4.39	4.50
19	14	1.56	2.15	2.15	2.37	2.77	3.34	3.67	4.21	4.46	4.81	4.92
20	14	1.76	2.31	2.34	2.57	2.99	3.57	3.95	4.54	4.81	5.20	5.33
21	14	1.96	2.46	2.52	2.76	3.20	3.79	4.22	4.85	5.15	5.58	5.71
22	14	2.14	2.61	2.69	2.94	3.40	4.00	4.47	5.15	5.47	5.94	6.07
23	14	2.32	2.75	2.86	3.11	3.59	4.20	4.71	5.43	5.77	6.28	6.42
24	14	2.49	2.88	3.02	3.28	3.77	4.39	4.94	5.70	6.06	6.61	6.75
25	14	2.65	3.01	3.17	3.43	3.95	4.58	5.17	5.96	6.34	6.93	7.07
26	14	2.81	3.13	3.31	3.59	4.12	4.76	5.38	6.21	6.61	7.23	7.38
27	14	2.96	3.25	3.45	3.73	4.28	4.93	5.59	6.45	6.87	7.52	7.67
28	14	3.10	3.36	3.59	3.87	4.43	5.09	5.78	6.68	7.12	7.80	7.96
29	14	3.24	3.47	3.72	4.01	4.58	5.25	5.97	6.91	7.36	8.08	8.23
30	14	3.38	3.58	3.84	4.14	4.73	5.40	6.16	7.12	7.59	8.34	8.50
31	14	3.51	3.68	3.96	4.27	4.87	5.55	6.34	7.33	7.82	8.59	8.76
32	14	3.64	3.78	4.08	4.39	5.01	5.69	6.51	7.53	8.03	8.84	9.01
33	14	3.76	3.88	4.20	4.51	5.14	5.83	6.68	7.73	8.24	9.08	9.25
34	14	3.88	3.97	4.31	4.63	5.27	5.96	6.84	7.92	8.45	9.31	9.48
35	14	3.99	4.06	4.41	4.74	5.39	6.09	7.00	8.10	8.65	9.53	9.71
36	14	4.11	4.15	4.52	4.85	5.51	6.22	7.15	8.28	8.84	9.75	9.93
37	14	4.22	4.24	4.62	4.96	5.63	6.34	7.30	8.46	9.03	9.96	10.14

Table 5: Percentile of mitral annular plane systolic excursion (MAPSE) (millimeters) estimated fetal weight (EFW).

EFW, grams	n	Percentile										
		1	2.5	5	10	25	50	75	90	95	97.5	99
200–399	46	1.49	1.75	1.76	1.87	2.23	2.71	3.05	3.30	3.65	3.88	4.19
400–599	34	2.16	2.36	2.48	2.65	3.10	3.64	4.15	4.56	4.95	5.38	5.70
600–799	26	2.55	2.72	2.91	3.11	3.61	4.19	4.79	5.30	5.71	6.26	6.57
800–999	20	2.82	2.97	3.21	3.43	3.98	4.57	5.25	5.82	6.24	6.88	7.19
1,000–1,199	15	3.04	3.17	3.44	3.68	4.26	4.87	5.60	6.23	6.66	7.36	7.68
1,200–1,399	18	3.22	3.33	3.63	3.89	4.49	5.12	5.89	6.56	7.00	7.76	8.07
1,400–1,599	22	3.36	3.47	3.79	4.06	4.68	5.33	6.14	6.84	7.29	8.09	8.40
1,600–1,799	12	3.49	3.58	3.93	4.21	4.85	5.51	6.35	7.08	7.54	8.38	8.69
1,800–1,999	9	3.61	3.69	4.05	4.34	5.00	5.67	6.53	7.30	7.76	8.63	8.95
2,000–2,199	12	3.71	3.78	4.16	4.46	5.13	5.81	6.70	7.49	7.96	8.86	9.17
2,200–2,399	18	3.80	3.86	4.26	4.57	5.25	5.94	6.85	7.66	8.14	9.07	9.38
2,400–2,599	14	3.88	3.94	4.35	4.67	5.36	6.05	6.99	7.82	8.30	9.25	9.57
2,600–2,799	13	3.96	4.01	4.44	4.76	5.46	6.16	7.12	7.96	8.45	9.43	9.74
2,800–2,999	9	4.03	4.07	4.51	4.84	5.55	6.26	7.24	8.10	8.59	9.59	9.90
3,000–3,199	8	4.10	4.14	4.59	4.92	5.64	6.35	7.35	8.22	8.72	9.74	10.05
3,200–3,399	2	4.16	4.19	4.65	4.99	5.72	6.44	7.45	8.34	8.84	9.88	10.19
3,400–3,599	2	4.22	4.25	4.72	5.06	5.80	6.52	7.54	8.45	8.95	10.01	10.32
≥3,600	0	4.27	4.30	4.78	5.12	5.87	6.60	7.63	8.55	9.06	10.13	10.44

those of the normal reference range [4, 5]. These findings underscore the clinical utility of TAPSE and MAPSE for assessing fetal systolic function under various conditions. Consequently, establishing robust reference ranges is

crucial for the accurate diagnosis and effective monitoring of fetal systolic cardiac function.

To the best of our knowledge, our study represents the largest dataset of normal reference ranges in a Southeast

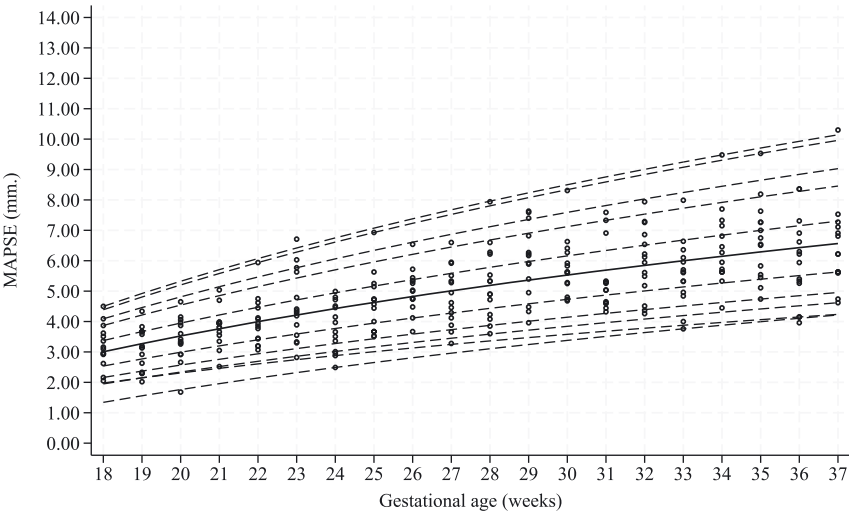


Figure 4: Scatterplots of mitral annular plane systolic excursion (MAPSE) based on gestational age (GA) in the study population. Estimated 1st, 2.5th, 5th, 10th, 25th, 50th, 50th, 75th, 90th, 95th, 97.5th, and 99th percentiles curves are shown.

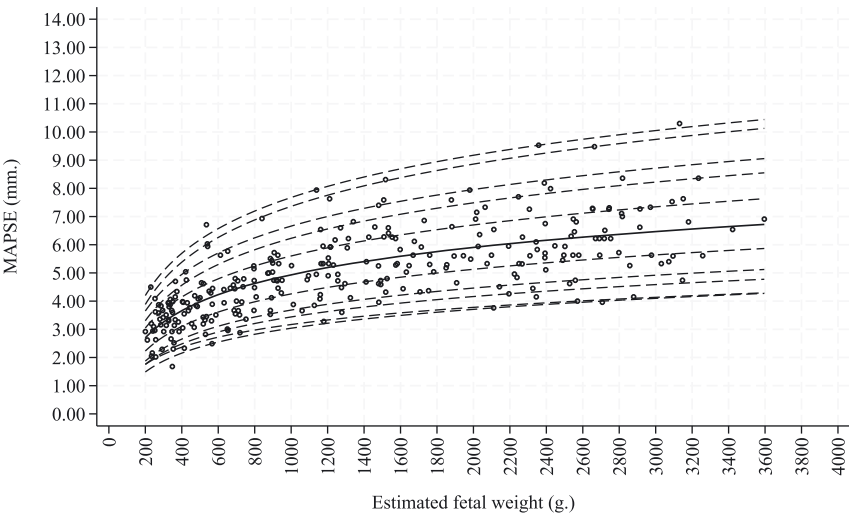


Figure 5: Scatterplots of mitral annular plane systolic excursion (MAPSE) based on estimated fetal weight (EFW) in the study population. Estimated 1st, 2.5th, 5th, 10th, 25th, 50th, 50th, 75th, 90th, 95th, 97.5th, and 99th percentiles curves are shown.

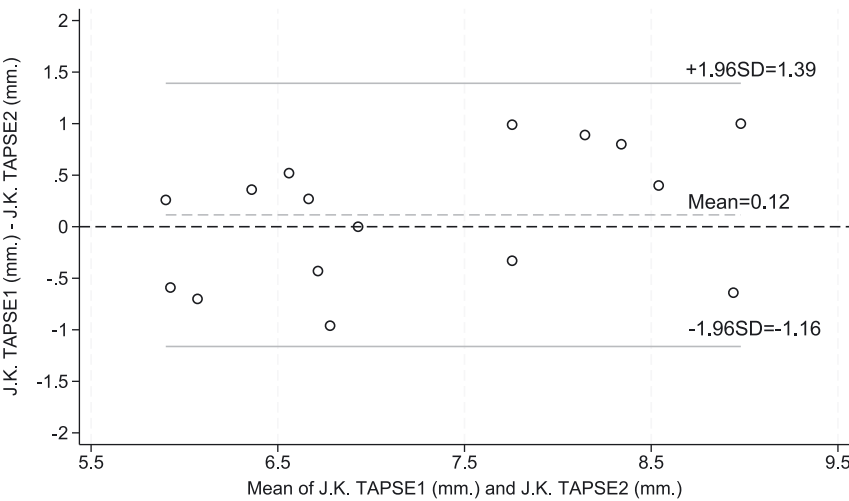


Figure 6: Bland–Altman plot demonstrating intra-observer agreement of tricuspid annular plane systolic excursion (TAPSE) measurements.

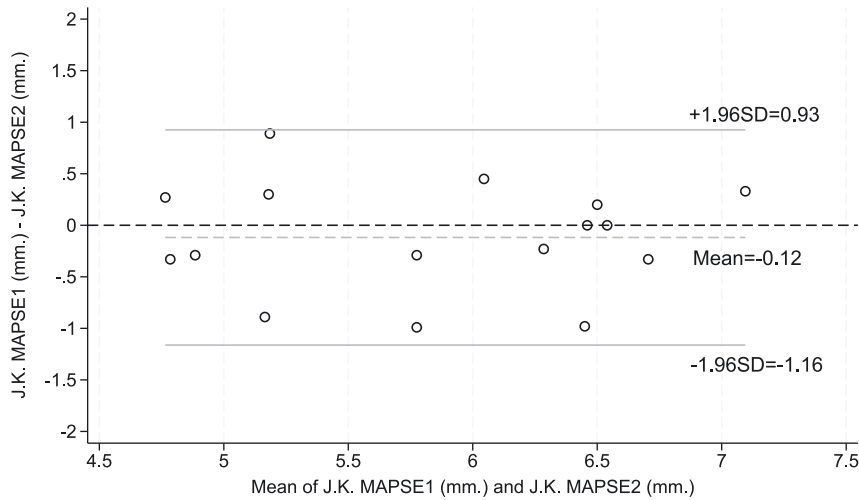


Figure 7: Bland-Altman plot demonstrating intra-observer agreement of mitral annular plane systolic excursion (MAPSE) measurements.

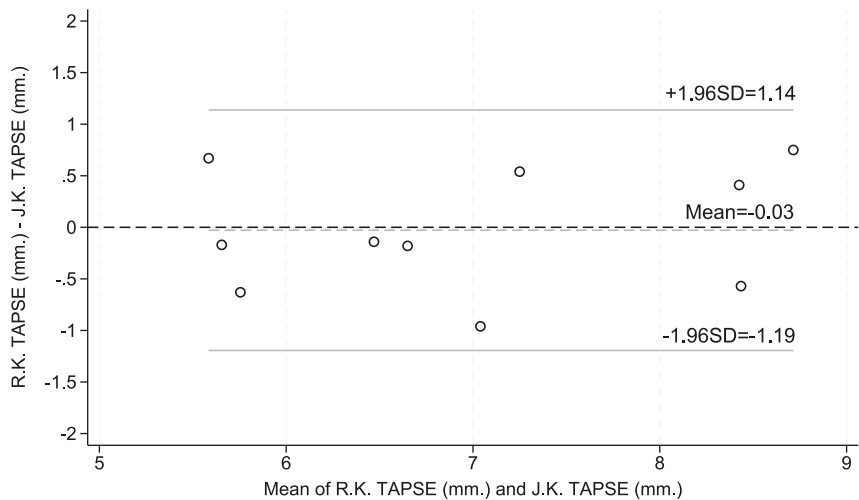


Figure 8: Bland-Altman plot demonstrating inter-observer agreement of tricuspid annular plane systolic excursion (TAPSE) measurements.

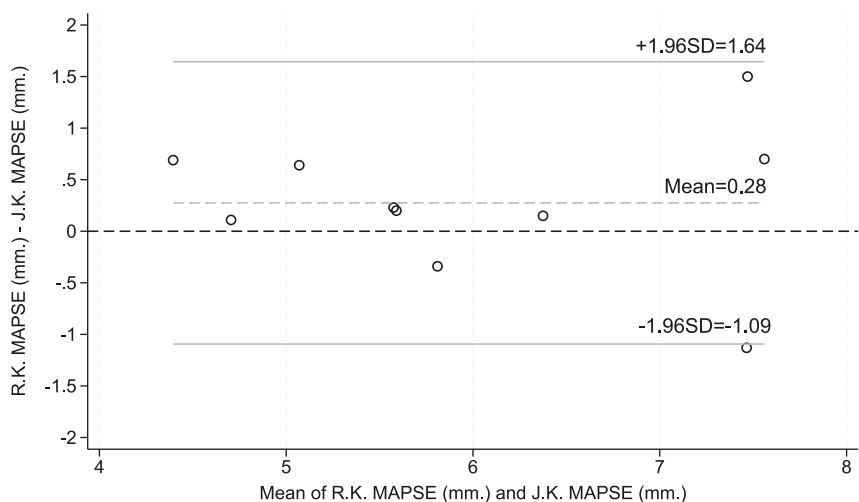


Figure 9: Bland-Altman plot demonstrating inter-observer agreement of mitral annular plane systolic excursion (MAPSE) measurements.

Asian population. Data collection began at 18 weeks' GA, earlier than in previous studies [19–21]. Establishing a reference for early GAs has significant advantages in the

early detection of fetal cardiac dysfunction, which may benefit the early management of conditions, such as TTTS [4, 5] and early FGR [3, 26].

Currently, various methods are available to assess fetal cardiac function, including M-mode for TAPSE, MAPSE, and shortening fraction; and B-mode and pulse-wave Doppler (PWD) for stroke volume, cardiac output, and myocardial performance index. Despite these options, no standardized method for fetal cardiac assessment has been established [6]. Our study specifically focused on the annular plane systolic excursion using the M-mode due to its simplicity, ease of measurement and interpretation, and availability on all ultrasound devices. Additionally, it does not require advanced ultrasonography skills, making it a practical and sensitive tool for detecting cardiac dysfunction. Our study provided an ICC for inter-observer variability, indicating that the measurement method was reproducible.

A key consideration when using conventional M-mode is that the M-mode cursor must be parallel to the interventricular septum. Deviations from this alignment increase measurement errors. Previous studies comparing conventional M-mode to angular M-mode have shown that TAPSE and MAPSE values remain nearly identical when the cursor-interventricular septum angle is maintained $<30^\circ$ [19]. Our study optimized accuracy by maintaining an insonation angle $<15^\circ$, which provides a reliable reference range.

Strengths and limitations

Strengths of this study are the largest prospective cross-sectional assessment and a good intraclass correlation coefficient of TAPSE and MAPSE in normally developing fetuses among pregnant women in Southeast Asia. Additionally, data collection as early as 18 weeks' GA enabled early detection of fetal cardiac dysfunction. All participants were followed-up postpartum to ensure that their newborns had normal birth weights and no abnormalities on physical examination. However, this study had some limitations, the first of which were its single-center design including only a Southeast Asian population without postnatal fetal echocardiography for confirmation. Further research involving more ethnically diverse populations is required to establish robust reference values that can be widely applied to various ethnic groups. And, external validation of our reference using standardized tools within our population is necessary to confirm applicability and reliability.

Conclusions

In summary, the present investigation established normal reference ranges for TAPSE and MAPSE to assess fetal systolic cardiac function. TAPSE and MAPSE increased with

advancing GA and fetal weight. These parameters are simple, easy to use, and convenient for evaluating ventricular systolic function. They can be used to assess fetal cardiac function in conditions such as FGR, congenital cardiac anomalies, fetal and placental tumors, fetal anemia, and TTTS.

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Research ethics: The study was approved by the Khon Kaen University Ethics Committee for Human Research (Reference number HE661527) and was conducted in accordance with the Declaration of Helsinki (as revised in 2013) and the International Council for Harmonization Good Clinical Practice Guidelines.

Informed consent: Informed consent was obtained from all individuals included in this study.

Author contributions: All authors have accepted responsibility for the entire content of this manuscript and approved its submission. J.K. and R.K. conceptualized the study, collected and analyzed the data, validated the findings, and wrote the original draft. P.S., K.K., S.C., C.D., and T.W. contributed to data collection.

Use of Large Language Models, AI and Machine Learning Tools: None declared.

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Data availability: The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

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