Cervical Strain Values Measured by Ultrasonographic Elastography in Pregnant Women between 18 and 40 Weeks' Gestation

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Objective: *To evaluate the reproducibility, examine the cervical tissue strain using sonographic elastography, and investigate the factors affecting the cervical tissue strain in pregnant women.*
Material and Method: *A cross-sectional study of 116 pregnant women at 18 to 40 weeks of gestation between September 1, 2014 and January 31, 2015 was done. Transvaginal manual compression elastographic examinations of the uterine cervices were performed in three planes, one mid-sagittal, and two cross-sectional planes at the level of internal os and external os. The intra-observer and inter-observer reliabilities were evaluated. The mean cervical strain values in the seven gestational age groups and four cervical length group were examined. Finally, the associations between cervical strain values and maternal age, maternal BMI, parity, gestational age, and cervical length were investigated.*
Results: *Intra-observer and inter-observer reliabilities were highest at proximal portion of anterior lip in sagittal plane and endocervical canal of internal os in cross-sectional plane. Cervical length had moderate negative correlation with gestational age and cervical strain values while cervical strain values had moderate positive correlation with gestational age.*
Conclusion: *Cervical elastography has good intra-observer and inter-observer reliabilities. The cervical strain values at proximal portion of anterior lip in sagittal plane and endocervical canal of internal os in cross-sectional plane have positive correlation with gestational age and negative correlation with cervical length.*

Keywords: *Cervical elastography, Cervical strain, Cervical length*

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The cervix is a crucial part of the uterus and has an important role throughout pregnancy. The transformation of the cervix is a dynamic process called cervical remodeling that is the key to successful pregnancy. It starts early in the first trimester, divided into four stages termed, softening, ripening, dilatation, and postpartum repair(1-3). These changes are associated with the decreased tensile of the collagen contents that is the predominant components of the extracellular matrix of the cervix.

According to the American College of Obstetricians and Gynecologists (ACOG)(4), the short cervix, measured between 16 and 22 weeks' gestations, is the only powerful sonographic predictor of spontaneous preterm births. Otherwise, the majority of preterm births occur in pregnant women with normal cervical length(5). Therefore, cervical shortening is not the only phenomenon associated with preterm births. The complexity of cervical remodeling need to be explored.

Cervical elastography using transvaginal ultrasonography is a tool in the assessment of cervical stiffness. Several studies were performed to investigate its implication for detecting abnormality of the cervix and predicting the success of labor induction(6). The elastography has been studied for early detection of malignancy in prostate, breast, liver, and thyroid. It required specialized software to produce a color map that describes deformation of the tissue relative to neighboring areas. These rate-of-change values are called "strain values" and are displayed in color map to give an elastographic image on a continuous spectrum ranging from red, yellow, and green to blue for softer to harder tissues, respectively, and measure the displacement of the tissue after application of pressure, which can be expressed as strain values or ratio. Strain value is greater in softer tissue than harder tissue. Currently, there are three methods for cervical

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elastography, the first method was proposed by Hernandez-Andrade et al[11], the second method was proposed by Molina et al[9], and the last method was proposed by Wozniak et al[12] and Swiatkowska-Freund and Preis[14].

The aim of the present study was to examine the cervical strain values in pregnant women using ultrasonographic elastography and investigate the factors affecting the cervical tissue strain.

Material and Method

This was a cross-sectional study performed at the Maternal-Fetal Medicine Unit, Siriraj Hospital, Bangkok, Thailand. The sample size was calculated by using the pilot study (n = 30) performed previously by the authors, which found positive correlation with Pearson's correlation coefficient (r) of 0.7. The authors used nQuery Advisor program and defined 2-sided type I error of 0.05 and power of 90 to prove the hypothesis of H0: $\rho = 0.5$, H1: $\rho = 0.7$. The result was n = 107. With an estimated 10% in dropout rate, the sample size of 116 was obtained. Pregnant women coming for a routine scan were asked to participate in the present study. Inclusion criteria were, age 18 years old or more, singleton, and gestational age between 18 and 40 weeks. The exclusion criteria included complicated pregnancy, pregnancy with fetal anomalies, previous cervical surgery, progesterone supplement during pregnancy, and unavailable delivery outcomes of this pregnancy.

The following data were recorded, maternal age, maternal body mass index (BMI), obstetrical history, gestational age at examination, cervical length, cervical strain values, gestational age at delivery, and delivery outcomes.

All patients provided a written informed consent approved by the Siriraj Hospital's Ethic Committee (IRB 404/2557). No patient had symptoms of labor pain, vaginal bleeding, and leakage or ruptured of membrane during examination.

Ultrasonographic examinations were performed transabdominally for confirmation of fetal viability, gestational age, anomaly, and well-being. Transvaginal ultrasonography for cervical examinations were performed by one of the authors (Wongsaroj P, 5 years of experience in ultrasound). The equipment used was a GE Voluson E6 ultrasound system (General Electric, Zipf, Austria) equipped with transvaginal transducer. The pregnant women were in the dorsal lithotomy position with an empty bladder. The vaginal probe was slowly introduced and placed in the anterior fornix of the vagina avoiding undue pressure on the cervix. The cervical length was measured as the shortest of three measurements taken between calipers placed at the internal os and external os measured in a sagittal view of the cervix[7,8]. After measurement of cervical length, the elastography was performed by the same machine using "elastography analysis software" (General Electric), which was already integrated in the machine by the manufacturer. It was done in three anatomical planes, one mid-sagittal view and two cross-sectional views at the level of internal os and external os. The probe was advanced into the cervix to produce compression. The quantity of pressure applied was displayed as a pressure bar in real-time on the screen to semi-quantify the technique and the cine loop data was stored in the hard disk for further off-line analysis.

From the waveforms of compression-decompression cycles displayed on the screen during off-line analysis of stored cine loop database, the author selected the most symmetrical waveform and compare the strain signals at the peak of the compression for analysis using "elastography generic measurement software" (General Electric). Ten regions of interest (ROI) were chosen. Firstly, in mid-sagittal view, the four ROI of the cervix: distal portion of anterior lip (Region A), proximal portion of anterior lip (Region B), proximal portion of posterior lip (Region C), and distal portion of posterior lip (Region D) (Fig. 1) were selected. The 5-mm diameter sampling circle was placed in each of the four regions, the machine then analyzed

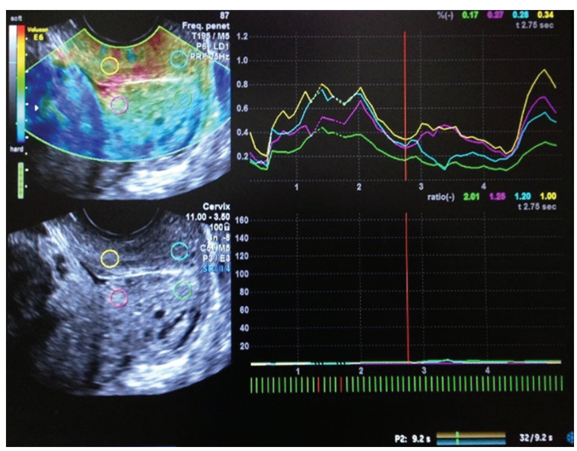

Fig. 1 Cervical strain measurements in mid-sagittal plane with 4 regions of interest: external superior lip of cervix (Region A), internal superior lip of cervix (Region B), external inferior lip of cervix (Region C), and internal inferior lip of cervix (Region D).

a strain value for each region automatically. The second step in the same mid-sagittal view, the strain of the two ROI of the cervix, endocervical canal (Region E) and entire cervix (Region F), were calculated by using the tracing tool provided by the machine. The endocervical canal was defined as the area approximately 2 mm around the midline echo along the cervical length (Fig. 2). In the cross-sectional view, the four ROI of the cervix, endocervical canal and entire cervix at the level of internal os (Region G, Region H, respectively), and external os (Region I, Region J, respectively) were selected and the strains were calculated by using the tracing tool. The endocervical canal was defined as 2-mm diameter circle at the central portion of cervix (Fig. 3). The measured strain values were displayed. The higher value represents the soft tissue, the lower value represents the hard tissue.

In 20 cases, the second author (Moungmaithong S) performed the cervical strain calculation from the stored database acquired by the first author, blinded to measurements from the first author. Two regions with highest inter-observer reliability will be used for further analysis.

Statistical analysis

Analyzes were performed using PASW Statistics 18.0. Continuous variables are expressed as mean ± SD or median and range. Qualitative variables are expressed as n (%). Pearson's correlation coefficient was used to assess the correlation between cervical strain values and gestational age, correlation between cervical strain values and cervical length.

The intra-observer and inter-observer reliabilities of measurements were assessed using intra-class correlation coefficient (ICC) with 95% CI. High reliability was defined as ICC >0.7.

For multiple comparison, one-way ANOVA was performed to compare the mean cervical strain values in the seven different gestational age groups and four different cervical length group.

Multiple linear regression analysis was used to examine the association between cervical strain values and following factors: maternal age, maternal BMI, parity, gestational age, cervical length. Statistical significance was defined as a *p*-value <0.05.

Results

Between September 2014 and January 2015, 116 pregnant women met the inclusion criteria and agreed to participate in the present study. Delivery outcomes were available in all 116 cases. Demographic data and obstetric history were shown in Table 1. The median gestational age at delivery was 39 weeks (range 37.0 to 41.6 weeks). Seventy-four (63.8%) of them delivered by vaginal route. The median birth weight of the newborn was 3,065 g (range 2,020 to 4,160 g).

The intra-observer and inter-observer reliability obtained from 20 women are shown in Table 2. The inter-observer reliability was highest in Region B and Region G (ICC = 0.88 and 0.85, respectively). The cervical strain values from these two regions were used for further analysis in the present study.

There was moderate positive correlation between cervical strain values of these two regions

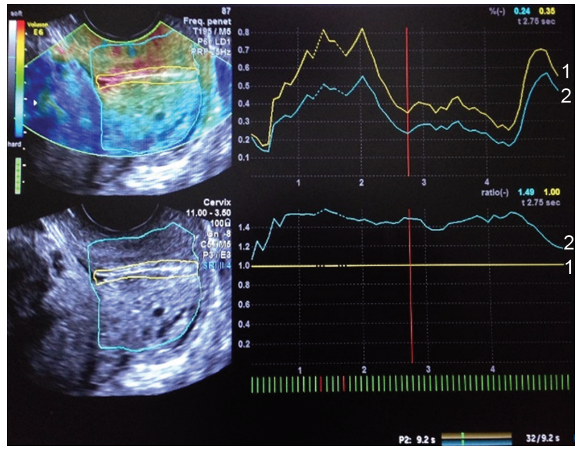

Fig. 2 Cervical strain measurements in mid-sagittal plane with 2 regions of interest: endocervical canal (1: yellow line), entire of cervix (2: blue line).

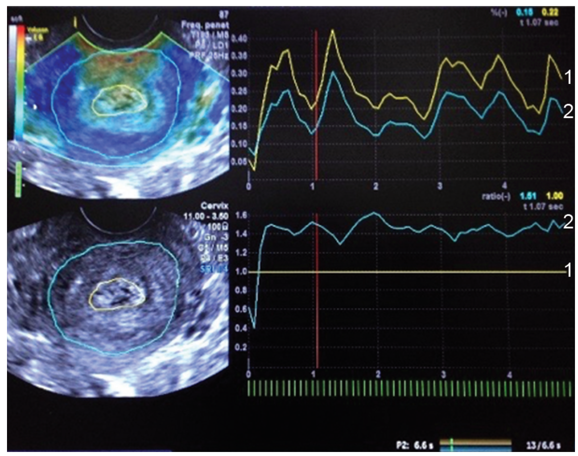

Fig. 3 Cervical strain measurements in cross-sectional plane with 2 regions of interest: endocervical canal (1: yellow line), entire of cervix (2: blue line).

and gestational age (r = 0.447 and 0.509, respectively) as shown in Fig. 3. The mean cervical strain values in these two regions in categorical gestational age (Table 3). The mean cervical strain values in Region B differed significantly by categorical gestational age (p<0.001). The pairwise multiple comparison was statistically significant between group 1 and 6, 7 (p = 0.026, 0.015), group 2 and 5, 6, 7 (p = 0.006, 0.003, 0.002), group 3 and 6, 7 (p = 0.019, 0.011). The mean cervical strain values in Region G also differed significantly by categorical gestational age (p<0.001). The pairwise multiple comparison was statistically significant between group 1 and 5, 6, 7 (p = 0.005, <0.001, <0.001), group 2 and 7 (p = 0.022), group 3 and 6, 7 (p = 0.025, 0.007).

The present study showed moderate negative correlation between cervical length and gestational age (r = -0.329) as in Fig. 4 and moderate negative correlation between cervical strain values of Region B and Region G (r = -0.376 and -0.327, respectively) (Fig. 5) and cervical length (Fig. 6). The mean cervical strain values in Region B differed significantly by categorical cervical length (p<0.001). The pairwise multiple comparison was statistically significant between group 1 and 4 (p = 0.027), group 2 and 3, 4 (p = 0.023, <0.001) and the mean cervical strain values in Region G also differed significantly by categorical cervical length (p<0.001). The pairwise multiple comparison was statistically significant between group 1 and 3, 4 (p = 0.005, 0.001), group 2 and 3, 4 (p = 0.049, 0.011) (Table 4).

As shown in Table 5, multiple linear regression analysis showed cervical strain values in Region B and

Table 1. Pregnancy characteristics in the population (total n = 116)

Characteristic	Median (range) or n (%)
Maternal age (years)	27.0 (18.0 to 40.0)
Body mass index (BMI) (kg/m^2)	21.2 (13.6 to 37.4)
Nulliparous (cases)	51 (44.0)
Gestational age (GA) at examination (weeks)	31.2 (18.0 to 40.0)
Cervical length (mm)	34.65 (10.2 to 61.1)
Prior spontaneous preterm delivery (cases)	5 (4.3)
Prior cesarean section (cases)	11 (9.5)

Table 2. Intraclass correlation coefficients (ICC) of elastography in different regions of cervix

Region of cervix	ICC (95% CI)	
	Intra-observer	Inter-observer
Sagittal view		
External superior lip of cervix (Region A)	0.87 (0.75 to 0.94)	0.54 (0.19 to 0.76)
Internal superior lip of cervix (Region B)	0.98 (0.88 to 0.97)	0.88 (0.76 to 0.94)
External inferior lip of cervix (Region C)	0.92 (0.85 to 0.96)	0.79 (0.58 to 0.89)
Internal inferior lip of cervix (Region D)	0.91 (0.82 to 0.96)	0.50 (0.15 to 0.74)
Endocervical canal (Region E)	0.90 (0.81 to 0.96)	0.60 (0.29 to 0.80)
Entire cervix (Region F)	0.86 (0.73 to 0.93)	0.49 (0.13 to 0.73)
Cross-sectional view		
Internal os; endocervical canal (Region G)	0.85 (0.72 to 0.93)	0.85 (0.69 to 0.93)
Internal os; entire cervix (Region H)	0.80 (0.62 to 0.90)	0.42 (0.04 to 0.69)
External os; endocervical canal (Region I)	0.77 (0.58 to 0.88)	0.35 (-0.04 to 0.64)
External os; entire cervix (Region J)	0.82 (0.67 to 0.91)	0.45 (0.08 to 0.71)

Table 3. Mean cervical strain values in internal superior lip (Region B) and endocervical canal of internal os (Region G)

Group	GA (weeks)	n	Strain values in Region B (%)		Strain values in Region G (%)	
			Mean ± SD	p-value	Mean ± SD	p-value
1	18 to 20^{+6}	13	0.11±0.06	<0.001	0.14±0.06	<0.001
2	21 to 23^{+6}	12	0.09±0.04		0.19±0.06	
3	24 to 26^{+6}	10	0.10±0.07		0.18±0.08	
4	27 to 29^{+6}	17	0.11±0.06		0.21±0.06	
5	30 to 32^{+6}	24	0.18±0.09		0.24±0.08	
6	33 to 35^{+6}	22	0.23±0.14		0.27±0.09	
7	36 to 40	18	0.24±0.12		0.29±0.09	

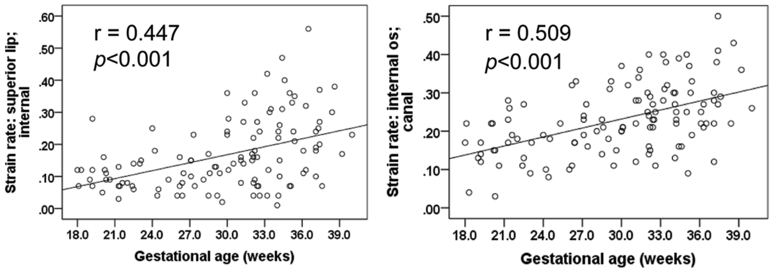

Fig. 4 a) Correlation between cervical strain in Region B and gestational age (left), and b) between cervical strain in Region G and gestational age (right).

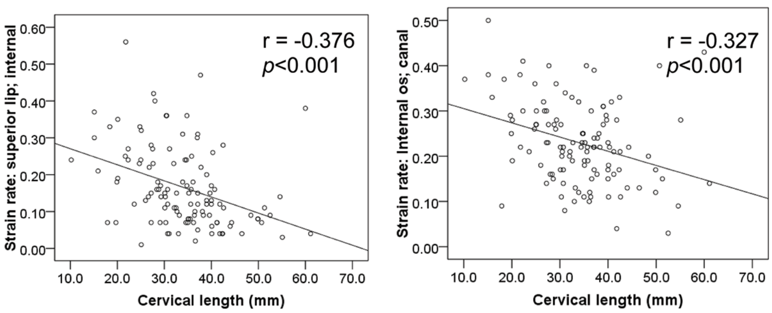

Fig. 5 a) Correlation between cervical strain in Region B and cervical length (left), b) between cervical strain in Region G and cervical length (right).

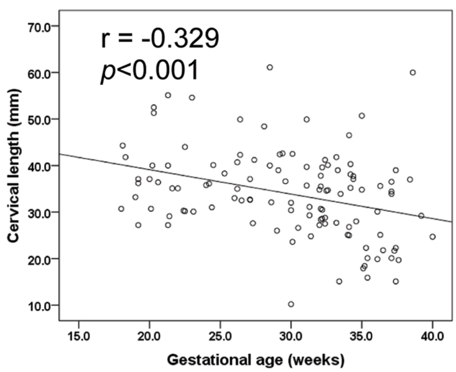

Fig. 6 Correlation between cervical length and gestational age.

Region G differed by gestational age significantly ($p<0.001$ and 0.001). The cervical strain values in Region B significantly correlated with cervical length ($p = 0.001$). The cervical strain values in Region G was marginally associated with cervical length ($p = 0.056$).

Discussion

Cervical elastography is a relatively novel and sophisticated means of ultrasound assessment of cervical tissue pre- and post-deformation. The degree of cervical tissue displacement after applying the pressure compared to neighboring areas is displayed as color map overlaid on the B-mode image. Cervical strain values can be automatically calculated by the specialized software.

The ROI selected for the measurements were different in the previous studies. The authors chose to combine two techniques presented by Molina et al[9] (four ROI in mid-sagittal plane that were similar to Region A, B, C, and D in the present study), and Hernandez-Andrade et al[10] (tracing method of entire cervix and endocervical os in both mid-sagittal plane and cross-sectional plane at the level of external os and internal os, which were similar to Region E, F, G, H, I, and J in the present study). The method presented by Wozniak et al[12], and Swiatkowska-Freund and Preis[14], was not used in the present study because the latter required the scoring system that was not practical and subjective. Both studies focused only the endocervical canal especially at the level of internal os which markedly overlapped with the previously selected ROI. However, the most representative and predictive ROI has not been validated.

The reproducibility of this technique has been explored by several previous studies. The authors found that the measurements are most reliable in two regions: internal superior lip and endocervical canal of internal

Table 4. Mean cervical strain values in internal superior lip (Region B) and endocervical canal of internal os (Region G)

Group	Cervical length (mm)	n	Strain values in Region B (%)		Strain values in Region G (%)	
			Mean ± SD	*p*-value	Mean ± SD	*p*-value
1	<20	8	0.22±0.11	<0.001	0.32±0.12	<0.001
2	20.1 to 30	28	0.23±0.12		0.27±0.07	
3	30.1 to 40	55	0.16±0.09		0.21±0.07	
4	>40	25	0.10±0.09		0.19±0.10	

Table 5. Correlation between cervical strain values in Region B, Region G, and factors

Factors	Strain values in Region B (%)		Strain values in Region G (%)	
	b	*p*-value	b	*p*-value
Age	-0.001	0.701	0.001	0.567
Body mass index	0.001	0.744	-0.002	0.292
Parity	0.007	0.699	-0.007	0.633
Gestational age	0.006	<0.001	0.007	<0.001
Cervical length	-0.003	0.001	-0.002	0.056

b = linear regression coefficient

os. Similarly, Molina et al observed that inter-observer agreement was highest in the internal superior region[9] and Hernandez-Andrade et al observed that inter-observer agreement was stronger for measurements obtained in the cross-sectional plane of the internal os[10].

The findings of the present study demonstrated that cervical strain values from transvaginal ultrasonography could represent the stiffness of cervical tissue. Our study shows positive correlation between cervical strain values and gestational age. This can be demonstrated in comparison between pregnant women with gestational age between 18 and 21 weeks and those with gestational age of more than 33 weeks. These findings opposed a study from Hernandez-Andrade et al, which demonstrated that gestational age was not significantly associated with cervical tissue strain[11]. This could be a result from difference in sample size, sample distribution, and range of cervical length. On the other hand, the cervical strain values had negative correlation with cervical length similar to the previous studies from Hernandez-Andrade et al[10,11] and Wozniak et al[12]. These findings could be explained from mechanism of cervical remodeling. Cervical softening begins early in the first trimester of pregnancy. It is a slow and incremental process taking place in a progesterone-rich environment. Cervix increase in compliance but tissue competence is maintained. Followed the softening, the loss of progesterone function is mediated during the phases of cervical ripening and dilatation. Ripening is more accelerated, occurs in the weeks or days preceding birth. It is characterized by maximal loss of tissue compliance and integrity related to collagen degradation by collagenases of the matrix metalloproteinase (MMP) family[1]. This process could associate the cervical strain with the gestational age and cervical length.

Currently, prior preterm birth is one of a strongest risk factor[14] while a short cervix in the second trimester is the best predictor of spontaneous preterm birth. Related to cervical remodeling, the cervical elastography may have a role for screening in pregnant women with risk of preterm birth since the softening occurs prior to cervical shortening as Wozniak et al reported that preterm deliveries were significantly higher in pregnant women with soft cervix determined by elastography of internal cervical os at 18 to 22 weeks of pregnancy[12]. Unfortunately, the correlation between cervical elastography and preterm birth could not be evaluated in the present study due to small size of population and no preterm delivery found. Even though cervical factors are strong predictors, the pathogenesis of preterm delivery is multifactorial and the other risk factors should be evaluated for effective prediction and prevention of preterm birth.

The weakness of cervical elastography for clinical usage is lacking standardization. Currently, there is no definite boundary of ROI, method of measurement and reference tissue strain. We propose two ROI: internal superior lip and endocervical canal of internal os, due to highest inter-observer agreement. We use the same approach as Molina et al[9]. Since the degree and waveform of compression were displayed as indicator on the monitor of ultrasound machine, the quantity of compression could be partially controlled. However, with elastography, we cannot provide the equal pressure distribution applied to each region throughout the entire cervix. Anterior lip and distal portion, which directly contact with the probe, are more susceptible for the force applied and more likely to represent lower stiffness compared with deeper and laterally located tissue. Several approaches to standardize this technique were proposed and debated[9,16,17]. Unfortunately, no definite conclusion can be drawn at this moment.

In contrast to Young's modulus which was used to study strain in object when the deforming force being applied to the opposite faces as in elastography, the shear wave speed (SWS) approach which based on shear modulus which was used to study strain in object when the deforming force being applied tangentially may provide more reliable data. Instead of using compression, this emerging technique use ultrasound waves that were generated by the machine. The waves propagate radially throughout the cervical tissue and could be detected by the detecting waves generated. The tissue softness within the context of cervical heterogeneity could be obtained[16].

Our study had some limitations. First, this was a cross-sectional study design with small size of population. The inter-observer evaluation performed only the process of strain measurement and calculation because the second author (Moungmaithong S) was not available during the ultrasonographic examination. Evaluating the intra-observer and inter-observer reliability only on the stored datasets could provide inaccurate results, as the bigger problem was the acquisition of the raw data. Since no histological correlation of the findings were provided, the cervical strain may be inaccurate. Recent study revealed that ultrasonographic elastography of the uterine cervix held potential as a predictor of preterm delivery[11,18]. However, further prospective investigation with larger population is required to assess the clinical value of elastography as a tool for prediction of preterm delivery.

Conclusion

Cervical elastography has good intra-observer and inter-observer reliabilities. The cervical strain values at proximal portion of anterior lip in sagittal plane and endocervical canal of internal os in cross-sectional plane have positive correlation with gestational age and negative correlation with cervical length.

What is already known on this topic?

Cervical remodeling leads to decrease in tissue stiffness and results in cervical softening. Cervical elastography is a relatively new method for assessing cervical changes during pregnancy and can be measured by using transvaginal ultrasonographic technique with good intra-observer and inter-observer reliabilities.

What this study adds?

The authors presented normal reference ranges of the cervical strain values during 18 to 40 weeks of pregnancy and demonstrated that the cervical strain values at proximal portion of anterior lip in sagittal plane and endocervical canal of internal os in cross-sectional plane have the most measurement reproducibility. The present study also revealed that cervical stiffness decreases with gestational age and cervical length corresponds with the process of cervical remodeling, and may be a novel tool in predicting preterm birth.

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Potential conflicts of interest

None.

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ค่าความยืดหยุ่นของปากมดลูกจากการตรวจคลื่นเสียงความถี่สูงในสตรีตั้งครรภ์ในช่วงอายุครรภ์ 18 ถึง 40 สัปดาห์

พัชราภรณ์ วงศาโรจน์, สกิทา ม่วงไหมทอง

วัตถุประสงค์: *เพื่อศึกษาความยืดหยุ่นของปากมดลูกโดยการใช้คลื่นเสียงความถี่สูง (cervical elastography) ในสตรีตั้งครรภ์ไทยในแต่ละช่วงอายุครรภ์ และศึกษาปัจจัยที่มีผลต่อความยืดหยุ่นของปากมดลูก*

วัสดุและวิธีการ: *การศึกษาแบบ cross-sectional ในสตรีตั้งครรภ์เดี่ยวปกติอายุครรภ์ระหว่าง 18 ถึง 40 สัปดาห์ จำนวน 116 คน ที่มารับการตรวจด้วยคลื่นเสียงความถี่สูงที่หน่วยเวชศาสตร์มารดาและทารกในครรภ์ ในช่วงระหว่าง วันที่ 1 กันยายน พ.ศ. 2557 ถึง 31 มกราคม พ.ศ. 2558 สตรีกลุ่มตัวอย่างจะได้รับการตรวจด้วยคลื่นเสียงความถี่สูงผ่านทางช่องคลอดเพื่อเก็บข้อมูลความยาวของปากมดลูกและค่าความยืดหยุ่นของปากมดลูก จากการตรวจวัดใน 3 ระนาบ ได้แก่ แนวระนาบแบ่งครึ่งซ้ายขวา (mid-sagittal plane) ของปากมดลูก แนวระนาบตัดขวาง (cross-sectional plane) ในระดับรูเปิดด้านใน (internal os) และแนวระนาบตัดขวาง (cross-sectional plane) ในระดับรูเปิดด้านนอก (external os) ผู้นิพนธ์จะทำการตรวจความเชื่อถือได้ของการวัดค่าความยืดหยุ่นของปากมดลูก เปรียบเทียบค่าเฉลี่ยของความยืดหยุ่นในกลุ่มอายุครรภ์ 7 กลุ่ม และกลุ่มความยาวปากมดลูก 4 กลุ่ม รวมทั้งศึกษาความสัมพันธ์ระหว่างค่าความยืดหยุ่นของปากมดลูกกับปัจจัยต่าง ๆ ได้แก่ อายุมารดา ดัชนีมวลกาย จำนวนครั้งการตั้งครรภ์ อายุครรภ์ และความยาวปากมดลูก*

ผลการศึกษา: *ค่าความยืดหยุ่นจะมีความเชื่อถือได้สูงที่สุดในการวัดที่ตำแหน่งส่วนบนด้านในของปากมดลูก (internal superior lip) ในแนว mid-sagittal และตำแหน่งช่องปากมดลูกบริเวณรูเปิดด้านใน (endocervical canal of internal os) ในแนว cross-sectional ความยาวปากมดลูกมีความสัมพันธ์เชิงลบระดับปานกลางกับทั้งอายุครรภ์และค่าความยืดหยุ่นของปากมดลูก ในขณะที่ค่าความยืดหยุ่นของปากมดลูกมีความสัมพันธ์เชิงบวกระดับปานกลางกับอายุครรภ์*

สรุป: *ค่าความยืดหยุ่นของปากมดลูกจะมีความเชื่อถือได้สูงที่สุดในการวัดที่ตำแหน่งส่วนบนด้านในของปากมดลูก (internal superior lip) ในแนว sagittal และตำแหน่งช่องปากมดลูกบริเวณรูเปิดด้านใน (endocervical canal of internal os) ในแนว cross-section ค่าความยืดหยุ่นของปากมดลูกมีความสัมพันธ์ในเชิงบวกกับอายุครรภ์และมีความสัมพันธ์ในเชิงลบกับความยาวปากมดลูก*