Journal Pre-proof

Quantification of cervical stiffness changes in single and twin pregnancies using the E-Cervix technique

Yan Liu MD , Dan Yang MS , Yu Jiang MS , Qingxiong Yue MD

PII: S2589-9333(22)00234-8
DOI: https://doi.org/10.1016/j.ajogmf.2022.100804
Reference: AJOGMF 100804

To appear in: *American Journal of Obstetrics & Gynecology MFM*

Received date: 13 September 2022
Revised date: 31 October 2022
Accepted date: 5 November 2022

Please cite this article as: Yan Liu MD , Dan Yang MS , Yu Jiang MS , Qingxiong Yue MD , Quantification of cervical stiffness changes in single and twin pregnancies using the E-Cervix technique, *American Journal of Obstetrics & Gynecology MFM* (2022), doi: https://doi.org/10.1016/j.ajogmf.2022.100804

Manuscript Title

Quantification of cervical stiffness changes in single and twin pregnancies using the E-Cervix technique

Yan Liu MD[1+], Dan Yang MS[1+], Yu Jiang MS[1], Qingxiong Yue MD[2]*

Affiliations

[1]Department of Ultrasound, Dalian Women and Children's Medical Group, Dalian, China

[2]Department of Ultrasound, Dalian Municipal Central Hospital affiliated of Dalian Medical University, Dalian, China

[+]Yan Liu MD and Dan Yang MS contributed equally to this work.

*__Corresponding author__

Qingxiong Yue

Department of Ultrasound, Dalian Municipal Central Hospital

Address: No.826 Xinan Road Shahekou District, Dalian 116033, Liaoning Province, China.

Email: bjy77@163.com

Phone number: (86)1332-227-7229

Conflict of Interest：The authors report no conflict of interest.

Funding： This study was supported by grants from the Guide Project for the Science Foundation of Liaoning Province (2019-ZD-1019).

Word count: abstract: 434； main text: 2325

Condensation: Using E-Cervix for the Quantitative Assessment of Cervical Stiffness in Women with Singleton and Twin Pregnancies

Short Title: Cervical elasticity parameters of pregnant women

AJOG at a Glance:

A. Why was this study conducted?

Cervical length is a commonly used clinical indicator for evaluating preterm birth. However, some studies have shown that cervical length does not change in patients with cervical insufficiency. This study hopes to provide clinical reference values for cervical hardness at different gestational ages through quantitative evaluation of cervical stiffness to help predict premature birth.

B. What are the key findings?

Before 28 w, the cervical length of twin pregnancy was not different from that of singleton pregnancy, but the cervical elasticity parameters were significantly different from that of singleton pregnancy after 20 w.

C. What does this study add to what is already known?

The range of reference value of cervical elasticity of singleton and twins of different gestational ages and the cervical HR regression equation were convenient for clinical application.

Blinded Conflict of Interest Statement: The authors report no conflict of interest.

Keywords: cervix, E-Cervix, full term delivery, premature birth, singleton pregnancy, twin pregnancy

BACKGROUND: Cervical length is a commonly used clinical indicator for evaluating preterm birth. However, some studies have shown that cervical length does not change in patients with cervical insufficiency.

OBJECTIVE: To use transvaginal ultrasound E-Cervix to quantitatively evaluate the cervical stiffness in women with singleton and twin pregnancies so as to provide a reference for the clinical prediction of premature birth.

STUDY DESIGN: We collected cervical length (CL), cervical hardness ratio (HR), mean internal os strain (IOS), and mean external os strain (EOS) using transvaginal ultrasonographic E-Cervix assessments in pregnant women undergoing routine examinations in the Obstetrics Department of our hospital from January 2020 to December 2020. We summarized the range of cervical elasticity parameters at different gestational ages (GA) and compared the cervical elasticity parameters between singleton and twin pregnancies and between premature births and full-term births.

RESULTS: (1) A total of 988 pregnant women were enrolled in this study, and after exclusion, 770 were ultimately enlisted; (2) the inter-rater and internal consistency for various elasticity parameters were favorable; (3) cervical elasticity changes in women at full term showed some particular patterns. The declines in CL and HR were commensurate with GA, while IOS and EOS rose with increasing GA. The cervical HR in women with twin pregnancies was lower than in women with singleton pregnancies at the same GA, while the IOS in twin pregnancies was higher than in singleton pregnancies at the same GA ($P<0.05$). The CL of women with twin pregnancies was shorter than in singleton pregnancies at the same GA when the GA was ≥28 w (all $P<0.05$), and HR was linearly correlated with GA (r=0.68, r=0.71). The regression model for the cervical HR in singleton pregnancies was

HR=−0.8764×GA+100.99, while that for twin pregnancies was HR=−1.3037×GA+103.03. (4) When we compared cervical elasticity parameters between premature and full-term births, we noted that the cervical HR in pregnant women who exhibited premature births was lower regardless of whether they carried singleton or twin pregnancies (*P*=0.000 , *P*=0.000), while their IOS was higher (*P*=0.023, *P*= 0.000). We observed no significant differences when we compared the CL and EOS of pregnant women manifesting premature births vs. women with full-term births (*P*=0.216, *P*=0.345; *P*=0.475, *P*=0.363).

CONCLUSIONS: E-Cervix, when used for the quantification of cervical hardness, cervical-elasticity changes in full-term pregnant women showed some particular patterns. CL and HR diminished as GA increased, while IOS and EOS rose as GA increased; and the degree of these changes were larger in twin pregnancies. Pregnant women showing premature births exhibited a reduced cervical HR and augmented IOS relative to women experiencing full-term births.

Using E-Cervix for the Quantitative Assessment of Cervical Stiffness in Women with Singleton and Twin Pregnancies

Introduction

Cervical insufficiency refers to the weakness of the internal cervical os during the second trimester and prior to full-term birth leading to abortion or premature birth [1]. Premature birth is a significant factor that affects perinatal outcomes and neonatal prognosis [2]. The Bishop scoring system is commonly used in clinical practice for the subjective evaluation of cervical ripening, but cannot be applied to its comprehensive assessment [3-5]. In 1992, Jackson et al. first proposed using vaginal ultrasonography to measure cervical length (CL) for the prediction of premature birth [6], and this remains a widely used clinical practice. However, the authors of one study could not uncover any changes in the CL in a number of women with cervical insufficiency [7]. Hence, two-dimensional ultrasonographic evaluations are controversial in diagnosing cervical insufficiency. Transvaginal ultrasound E-Cervix is a technique that exploits the differences in sizes of deformation induced by cervical artery pulsation between cervices of different hardnesses, and enters these indices into multiparametric quantification of cervical hardness [8]. We herein adopted transvaginal ultrasound E-Cervix for the quantitative analysis of cervical hardness during pregnancy so as to provide a novel method for the clinical evaluation of cervical ripening.

Methods

1. Study participants

We collected data from pregnant women who underwent routine examination at the Obstetrics Outpatient Department of our hospital from January 2020 to December 2020. Our inclusion criteria were women who were primiparous; women who were experiencing a singleton pregnancy with a verified GA of 20 w+0 d–36 w+6 d, or undergoing a twin pregnancy with a verified GA of 20 w+0 d–34 w+6 d; a fetal size consistent with GA (±2 SD); and a healthy mother, with normal fasting blood glucose and blood pressure. Exclusion criteria for the pregnant women were the presence of a Nabothian cyst >1 cm, comorbid cervical lesions, the history of LEEP or cold knife cone , a uterine body or cervical malformation, cervical cerclage, or comorbid obstetric complications(hypertensive disorders complicating pregnancy, gestational diabetes mellitus, preterm premature rupture of the membranes, placental abruption), and women undergoing induced labor. Exclusion criteria regarding the fetus were structural abnormalities, polyhydramnios, and oligohydramnios.

2. Equipment and methods

We adopted the SAMSUNG WS80A ultrasound machine accessorized with a model EV3-10B probe that operated at frequencies of 3–10 MHz; and we applied the Elastoscan software. We first conducted a routine fetal examination in pregnant women as enrollment screening to uncover any exclusion criterion. The general data from pregnant women who were confirmed as enrolled were recorded, and E-Cervix software was used for cervical-elasticity examination and patient elasticity parameters were recorded. All images were obtained by a single sonographer. We then summarized the variations in the cervical-elasticity parameters with GA. At the start of the investigation we conducted a consistency analysis of E-cervix cervical-elasticity examinations performed on 32 pregnant women who met our enrollment criteria.

The cervical elasticity examination method we employed was as follows. After the pregnant woman had emptied her bladder, she adopted the lithotomy position; and an appropriate amount of disinfectant coupling gel was applied to the vaginal probe, which was then covered with a condom. The probe was placed in the vaginal fornix without pressure to first observe the morphology of the cervix and the presence or absence of space-occupying lesions prior to obtaining a midsagittal section of the cervix; thus, the cervix occupied over 1/3 of the visual display and clearly showed the cervical internal os, complete cervical-mucosa echogenic line, and cervical external os. The participant was instructed to relax and to breath calmly, at which time the probe was kept motionless and switched to elastography mode. The elasticity sampling frame included the entire cervix, and E-Cervix was then turned on for elastographic analysis. This status was maintained until the quality control bars were all green, at which point data acquisition was completed and the image was automatically saved. We obtained five elastographic images from each pregnant woman using the aforementioned method, and selected three satisfactory images from the last four images for the measurement of CL and the following elasticity parameters: the cervical hardness ratio (HR), mean internal os strain (IOS), and mean external os strain (EOS) (Figure 1). After measurement, means were calculated.

For the consistency test, operator A conducted an E-cervix cervical-elasticity examination on 32 pregnant women who met the enrollment criteria and whose images were retained. Operators A and B performed measurements and recordings, and neither operator knew the other's selected images nor the measurement results. The results of the two operators were thus used for inter-group comparisons. After two months, operator A executed a second measurement of the images saved from the 32 pregnant women, and an intra-group consistency comparison was adopted between these latter results and the first measurement results.

The diagnostic criterion for singleton premature birth was delivery at a GA <37 w. Considering that the average gestational week of delivery for twins was 35 w [9], the diagnostic criterion for twin premature birth was delivery at a GA<35 w.

3. Statistical methods

We employed SPSS v.22.0 for data analysis. The quantitative data we obtained were expressed as means ± standard deviation if they were normally distributed and expressed as medians (with minimum, maximum) if they did not follow a normal distribution. The intraclass correlation coefficient (ICC) was used for intra- and inter-group consistency analyses: an ICC >0.75 denoted good consistency, 0.04 ≤ICC ≤0.75 designated fair consistency, and an ICC <0.40 stipulated poor consistency. Independent sample *t* tests were used to test for differences between two groups for normally distributed quantitative data and the Wilcoxon signed-rank test was used to evaluate differences between two groups of non-normally distributed data. We applied Pearson correlation analysis to measure associations between parameters, and a difference of $P<0.05$ was considered to be statistically significant.

This study was approved by our ethics committee (2019047) and all participants signed informed consent forms.

Results

1. Patient inclusion/exclusion

A total of 988 pregnant women were enrolled in the present study. After exclusion, 770 were ultimately enrolled. We observed 545 singleton births, of which 509 were full-term and 36 were premature births; and there were 225 twin births, of which 95 were full-term and 130 were premature births (Figure. 2). Patient age ranged from 22 to 42 years, and mean age was 30.55±4.23 years. Table 1 and 2 show the general characteristics of the pregnant women.

2. Results of intra- and inter-group consistency analyses of elasticity parameters

The intra- and inter-group consistency analysis results with respect to elasticity parameters were good. The intra-group ICC ranged from 0.964 (95% CI, 0.927–0.982) to 0.992 (95% CI, 0.981–0.996), and the inter-group ICC ranged from 0.883 (95% CI, 0.775–0.941) to 0.986 (95% CI, 0.972–0.993) (Table 3).

3. Comparative analyses of cervical-elasticity parameters at different GAs in pregnant women who underwent full-term births, and between singleton and twin pregnancies

CL and HR declined as GA increased while IOS and EOS increased commensurately with the increase in GA. We also noted that the magnitude of changes in cervical-elasticity parameters in pregnant women with twins was greater than with singletons (Figure 3), with cervical HR showing a linear correlation with GA for both types of births (r=0.68, P<0.01 and r=0.71, P<0.01). We derived equations from our linear regression analysis, and cervical HR regression equation for singletons was HR= $-0.8764\times GA+100.99$, while that for twins was HR= $-1.3037\times GA+103.03$ (Figure 4).

We discerned no statistical difference in a comparison of cervical-elasticity parameters between mothers with singleton vs. twin pregnancies (P>0.05) in their CLs at a GA of 20 w+0 d–27 w+6 d, but noted statistical significance (P<0.05) at a GA ≥28 w. From 20 w onward, the cervical HR of women with twin pregnancies was lower than in singleton pregnancies of the same GA, while the IOS for twin pregnancies was higher than for singleton pregnancies at the same GA (P<0.05). There was no difference in cervical EOS between pregnant women with singleton vs. twin pregnancies (P>0.05) (Figure 3).

4. Comparison of cervical-elasticity parameters between pregnant women experiencing premature vs. full-term births.

We conducted a follow-up on women with singleton (n=545) and twin (n=225) pregnancies that revealed 36 and 130 singleton and twin premature births, respectively; and we compared cervical elasticity parameters between premature and full-term births, we noted that the cervical HR in pregnant women who exhibited premature births was lower regardless of whether they carried singleton or twin pregnancies (*P*=0.000, *P*=0.000), while their IOS was higher (*P*=0.023, *P*=0.000). We observed no significant differences when we compared the CL and EOS of pregnant women manifesting premature births vs. women with full-term births (*P*=0.216, *P*=0.345; *P*=0.475, *P*=0.363). (Tables 4 and 5).

Discussion

Principal findings

Cervical elasticity changes in women at full term showed some particular patterns. The declines in CL and HR were commensurate with GA, while IOS and EOS rose with increasing GA. Before 28 w, the CL of twin pregnancy was not different from that of singleton pregnancy, but the HR and IOS were significantly different from that of singleton pregnancy after 20 w.

Results in the context of what is known

The basic principle of elastography is based upon disparities in the deformation of tissues exhibiting differential elastic moduli when an external pressure is exerted on the tissue. Ultrasonographic elastography can be used to acquire echogenic signals of tissues before and after deformation, and the elastic modulus of tissues can then be calculated [10]. Transvaginal ultrasound E-Cervix differs from pressure elastography as manual pressure application to the cervix is not required, and this avoids instability in image quality due to uneven manual compression while simultaneously preventing cervical stimulation due to excessive pressure. The consistency tests in our study showed that the intra- and inter-rater consistencies were acceptable which was congruent with previous studies on cervical elastography [8,11]; and showed that transvaginal ultrasound E-Cervix can be used as a novel method for the quantitative evaluation of cervical hardness. In addition to the reliability of this technique, procurement of acceptable consistency may have been due to the fact that the two examiners analyzed and measured images acquired by a single person.

The basic criteria for pregnancy maintenance are dependent upon normal cervical structure and function. The measurement of CL is currently the primary method for cervical monitoring, and Park et al. proposed that CL can be used as an important marker for cervical evaluation [12]. In this study we demonstrated that CL diminished in both singleton and twin pregnancies as GA increased. However, while there was no statistical difference in CL between singleton and twin pregnancies at a GA <28 w, there was a difference when GA was ≥28 w. The elasticity parameter HR was also different between singleton and twin pregnancies before 28 w, which may be because the cervix may have undergone "physiologic remodeling" even when there is no change in CL. For example, increased matrix, collagen degradation, collagen-net loosening, and decreased matrix tension cause the cervix to become soft and short, and dilates the internal os [13,14]. Edgar et al. reported a weak correlation between CL and cervical hardness, and proposed that a long cervix may also reflect a soft cervix [15]. This study additionally revealed that the IOS for twin pregnancies was higher than for singleton pregnancies at the same GA. This result may have been due to elevated uterine cavity pressure, with internal os compression and stretching in twin pregnancies shown to be more severe than in singleton pregnancies at the same GA, therefore producing greater deformation. As the effect on the external os was lower, there was no noticeable difference in cervical EOS between twin and singleton pregnancies. We also observed that the magnitude of variation in cervical elasticity in pregnant women experiencing twin pregnancy was greater relative to singleton pregnancy, potentially because cervical compression was greater in twin pregnancy as GA increased.

Clinical and research implications

The singleton and twin preterm birth rates in our study were 6.6% and 57.8%, respectively. The preterm birth rate has been reported to be 8.2% for singletons and 60.3% for twins (delivering < 37 weeks) in the United States[16]. In singleton pregnancies, we had a slightly lower preterm birth rate, mainly because we excluded some cases of preterm birth due to obstetric complications. when we analyzed cervical-elasticity markers in pregnant women with premature births, we ascertained that cervical HR was reduced and IOS was elevated. We noted no differences in CL and EOS between pregnant women with premature births vs. full-term births. Therefore, we posit that it is not sufficiently accurate to use CL alone in predicting premature births, but that an additional quantitative evaluation of cervical hardness is required to predict such births. Since the risk of premature birth is high for twin pregnancies, it is therefore necessary to perform both cervical HR and IOS monitoring.

Strengths and limitations

In summary, assessment by transvaginal ultrasound E-Cervix can objectively reflect physiologic changes in the cervix during pregnancy and provide an important basis for the comprehensive evaluation of cervical ripening in clinical practice. This modality therefore possesses some clinical utility. The strengths of this study were as follows. (1) We were able to list the various cervical-elasticity parameters of singleton and twin pregnancies every week after 20 w; (2) a regression equation for HR and GA was established, providing a convenient method for the clinical evaluation of cervical hardness; and (3) the sample size for twin pregnancies in this study was higher compared with previous analyses of cervical elasticity. We do, however, acknowledge some limitations to our investigation: (1) this was a small, single-center study and a multicenter study with larger sample size is still needed in the case of twin pregnancies; (2) one operator acquired the images in the consistency study and this cannot reflect the actual inter-group consistency between two operators; and (3) even though ultrasonographic elastography has undergone rapid development in the last few years, imaging technology and data calculation and analysis still require additional development and improvement [17,18]. However, we posit that continuous maturation of this technology will ultimately show broad clinical applications in the evaluation of cervical function.

CONCLUSIONS: E-Cervix, when used for the quantification of cervical hardness, cervical-elasticity changes in full-term pregnant women showed some particular patterns. CL and HR diminished as GA increased, while IOS and EOS rose as GA increased; and the degree of these changes were larger in twin pregnancies. Pregnant women showing premature births exhibited a reduced cervical HR and augmented IOS relative to women experiencing full-term births.

References

1. Zhang L, Zheng Q, Xie H, Du L, Wu L, Lin M. Quantitative cervical elastography: a new approach of cervical insufficiency prediction. Arch Gynecol Obstet 2020;301:207-15.

2. Di Renzo GC, Cabero Roura L, et al. Preterm Labor and Birth Management: Recommendations from the European Association of Perinatal Medicine. J Matern Fetal Neonatal Med 2017;30:2011-30.

3. Garcia-Simon R, Oros D, Gracia-Cólera D, et al. Cervix assessment for the management of labor induction: reliability of cervical length and Bishop score determined by residents. J Obstet Gynaecol Res 2015;41:377-82.

4. Myers KM, Feltovich H, Mazza E, et al. The mechanical role of the cervix in pregnancy. J Biomech 2015;48:1511-23.

5. Hernandez-Andrade E, Garcia M, Ahn H, et al. Strain at the internal cervical os assessed with quasi-static elastography is associated with the risk of spontaneous preterm delivery at ≤34 weeks of gestation. J Perinat Med 2015;43:657-66.

6. Jackson GM, Ludmir J, Bader TJ. The accuracy of digital examination and ultrasound in the evaluation of cervical length. Obstet Gynecol 1992;79:214-8.

7. Hernandez-Andrade E, Hassan SS, Ahn H, et al. Evaluation of cervical stiffness during pregnancy using semiquantitative ultrasound elastography. Ultrasound Obstet Gynecol 2013;41:152-61.

8. Du L, Lin MF, Wu LH, et al. Quantitative elastography of cervical stiffness during the three trimesters of pregnancy with a semiautomatic measurement program: A longitudinal prospective pilot study. J Obstet Gynaecol Res 2020;46:237-48.

9. Gordon MC, McKenna DS, Stewart TL, et al. Transvaginal cervical length scans to prevent prematurity in twins: a randomized controlled trial. Am J Obstet Gynecol.

2016;214:277.e1-277.e7.

10. Ophir J, Céspedes I, Ponnekanti H, Yazdi Y, Li X. Elastography: a quantitative method for imaging the elasticity of biological tissues. Ultrason Imaging 1991;13:111-34.
11. Seol HJ, Sung JH, Seong WJ, et al. Standardization of measurement of cervical elastography, its reproducibility, and analysis of baseline clinical factors affecting elastographic parameters. Obstet Gynecol Sci 2020;63:42-54.
12. Park HS, Kwon H, Kwak DW, et al. Addition of Cervical Elastography May Increase Preterm Delivery Prediction Performance in Pregnant Women with Short Cervix: a Prospective Study. J Korean Med Sci 2019;34:e68.
13. Oxlund BS, Ørtoft G, Brüel A, et al. Collagen concentration and biomechanical properties of samples from the lower uterine cervix in relation to age and parity in non-pregnant women. Reprod Biol Endocrinol 2010;8:82.
14. Öcal FD, Çekmez Y, Erdoğdu E, et al. The utility of cervical elastosonography in prediction of cervical insufficiency: cervical elastosonography and cervical insufficiency. J Matern Fetal Neonatal Med 2015;28:812-8.
15. Hernandez-Andrade E, Maymon E, Luewan S, et al. A soft cervix, categorized by shear-wave elastography, in women with short or with normal cervical length at 18-24 weeks is associated with a higher prevalence of spontaneous preterm delivery. J Perinat Med 2018;46:489-501.
16. Roman A, Ramirez A, Fox NS. Prevention of preterm birth in twin pregnancies. Am J Obstet Gynecol MFM. 2022;4:100551.
17. Diawtipsukon S, Bumrungphuet S, Dulyaphat W, Panburana P. The Comparative Study of Cervical Shear Wave Elastography Between Twin and Singleton Pregnancy. Int J Womens Health 2020;12:649-56.

18. Chifan M, Tîrnovanu M, Grigore M, Zanoschi C. Cervical incompetence associated with congenital uterine malformations. Rev Med Chir Soc Med Nat Iasi 2012;116:1063-8.

Table1. The general characteristics of the pregnant women with full-term births

Parameters	Singleton pregnancy (n=509)	Twin pregnancy (n=95)	*P*
Age(years)	30.50±4.11	30.87±4.23	.774
GA(w)	28.89±5.23	27.89±4.47	.295
BMI(kg/m^2)	25.68±3.41	26.45±3.92	.514
FPG(mmol/L)	4.49±0.38	4.47±0.38	.607
SBP(mmHg)	109.98±6.13	110.78±5.99	.094
DBP(mmHg)	75.13±7.64	75.61±7.72	.431

GA: gestational ages; BMI: body mass index; FPG: fasting plasma glucose; SBP: systolic blood pressure; DBP: diastole blood pressure; GA and BMI were data at time of ultrasound, and FPG, SBP, and DBP were data at initial prenatal visit.

Table 2. The general characteristics of the pregnant women with Preterm births

Parameters	Singleton pregnancy (n=36)	Twin pregnancy (n=130)	*P*
Age(years)	31(26-36)	31.42±4.74	.324
GA(w)	28(21-35)	25.22±4.79	.000
BMI(kg/m^2)	26.43±3.87	27.30±4.05	.063
FPG(mmol/L)	4.45±0.27	4.46±0.28	.915
SBP(mmHg)	111.61±7.29	111.98±6.68	.771
DBP(mmHg)	74.83±7.55	74.71±6.86	.924

GA: gestational ages; BMI: body mass index; FPG: fasting plasma glucose; SBP: systolic blood pressure; DBP: diastole blood pressure; GA and BMI were data at time of ultrasound, and FPG, SBP, and DBP were data at initial prenatal visit.

Table3. Results of intra- and inter- observer consistency analyses of elasticity parameters

Parameters	Intra-observer ICC（95% CI）	Inter-observer ICC（95% CI）
CL	0.964（0.927,0.982）	0.883（0.775,0.941）
HR	0.990（0.980,0.995）	0.974（0.947,0.987）
IOS	0.992（0.981,0.996）	0.986（0.972,0.993）
EOS	0.991（0.980,0.996）	0.981（0.950,0.992）

CL: cervical length; HR: hardness ratio; IOS: mean internal os strain; EOS: mean external os strain

Table 4. Comparison of cervical-elasticity parameters between pregnant women experiencing premature vs. full-term births in pregnant woman with singleton pregnancy

Parameters	Full-term birth group (n=509)	Preterm birth group (n=36)	*P*
CL（cm）	4.05±0.71	3.67±0.48	.216
HR（%）	76.37±6.39	71.36±4.24	.000
IOS	0.22±0.06	0.26±0.04	.023
EOS	0.27±0.06	0.31±0.05	.345

CL: cervical length; HR: hardness ratio; IOS: mean internal os strain; EOS: mean external os strain

Table 5 Comparison of cervical-elasticity parameters between pregnant women experiencing premature vs. full-term births in pregnant woman with twin pregnancy

Parameters	Full-term birth group (n=95)	Preterm birth group (n=130)	*P*
CL（cm）	3.64±0.66	2.93±0.42	.475

HR（%）	68.13±7.00	51.48±4.53	.000
IOS	0.29±0.08	0.36±0.06	.000
EOS	0.31±0.08	0.38±0.08	.363

CL: cervical length; HR: hardness ratio; IOS: mean internal os strain; EOS: mean external os strain

Author Statement

Yan Liu (First Author): Conceptualization, Methodology, Funding acquisition, Writing- Reviewing and Editing

Dan Yang：Formal Analysis, Writing- Original draft preparation

Yu Jiang：Data Curation, Formal Analysis

Qingxiong Yue(Corresponding Author)：Conceptualization, Project administration, Supervision, Funding acquisition

Figure1. Cervical elasticity image of pregnant women at 25 weeks of gestation. Different colors indicated different tissue hardness, with red indicating the highest value and blue indicating the lowest value. A: singleton pregnancy, HR was 80.06%; B: twin pregnancy, HR was 71.07%. HR: hardness ratio

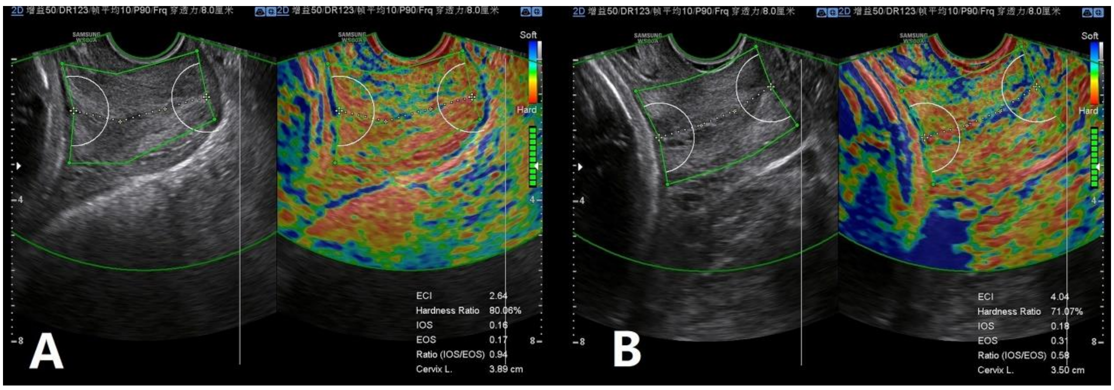

Figure2. Inclusion and exclusion of cases

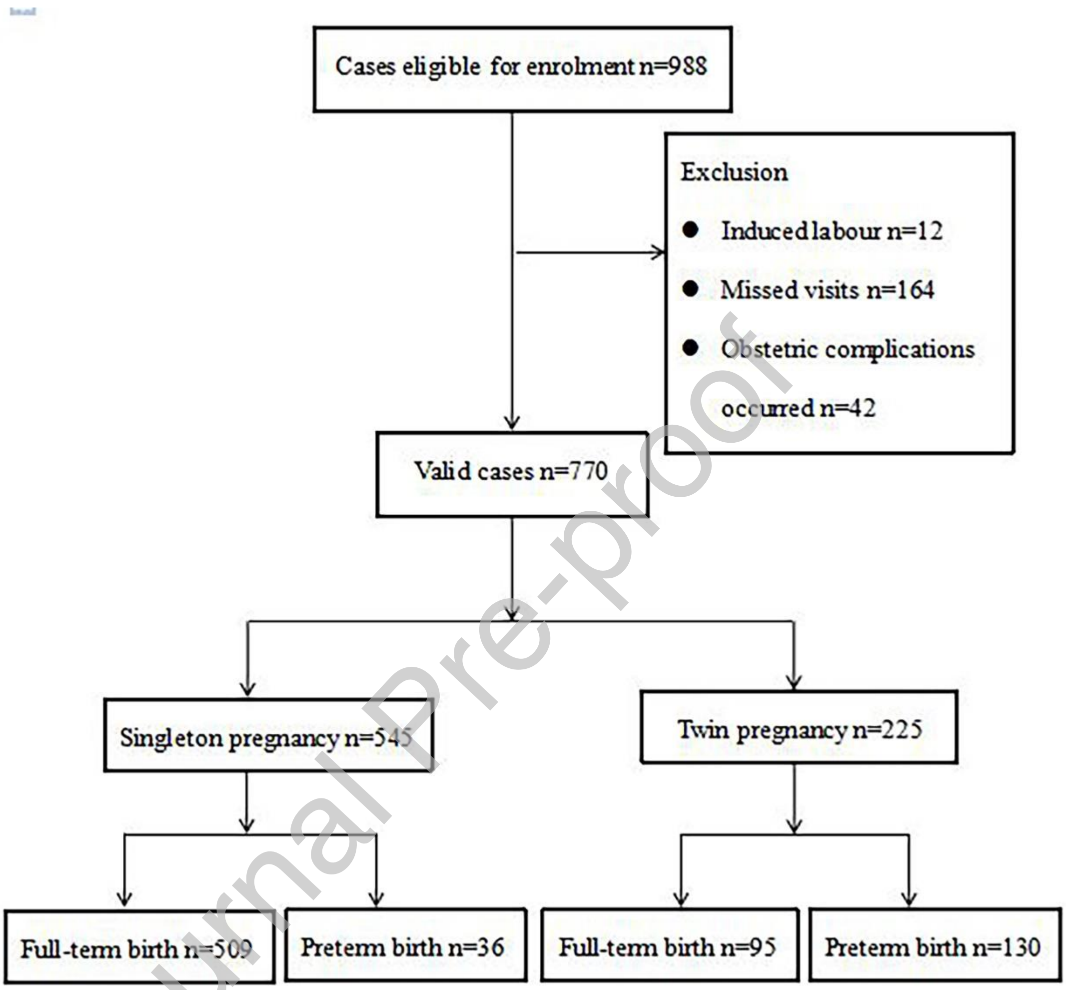

Figure3. Changes in cervical elasticity indicators during pregnancy in full-term pregnant women, the range of reference values and comparison of singleton and twin pregnancies. CL: cervical length; HR: hardness ratio; IOS: mean internal os strain; EOS: mean external os strain; ns: $P>0.05$; * $P<0.05$; ** $P<0.01$; *** $P<0.001$

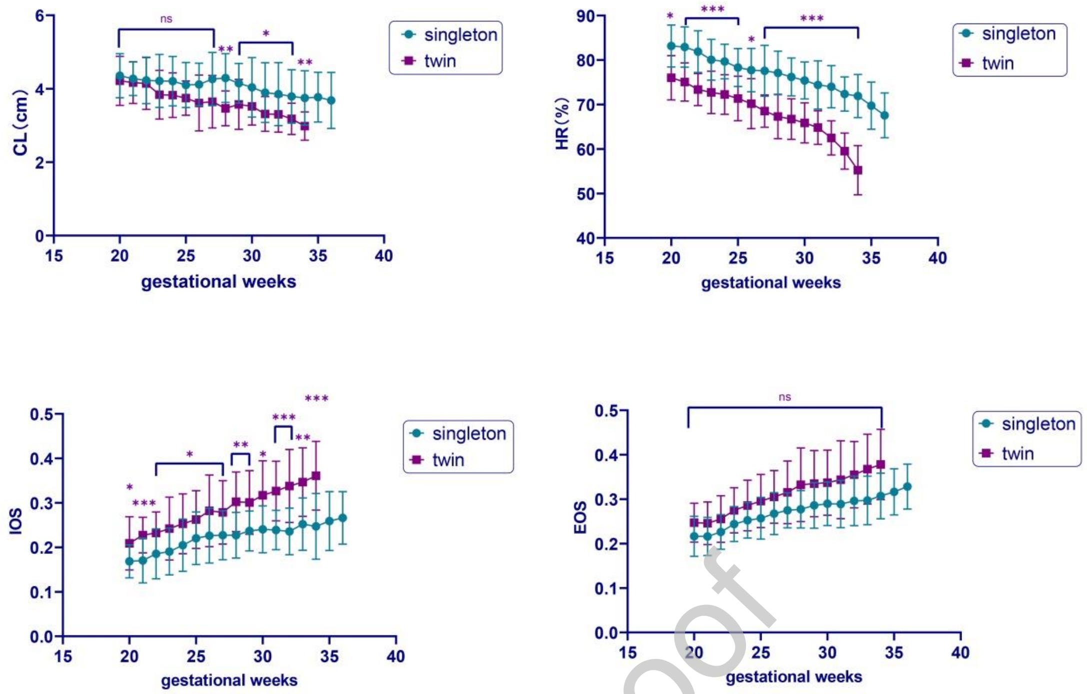

Figure4. Cervical HR is linearly correlated with gestational week in full-term pregnancies. A: singleton pregnancy; B: twin pregnancy. HR: hardness ratio