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RESEARCH

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Value of cervical strain in ultrasound elastography as a predictor of spontaneous preterm delivery

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Abstract

Background Cervical incompetence is a failure of the cervix to retain the products of conception throughout pregnancy, which results into cervical dilatation and preterm delivery. Many methods are conducted for early detection of cervical shortening, ripening and eventually dilatation to lessen the incidence of the preterm delivery, which is responsible for about 75% of neonatal comorbidities. Ultrasound plays an important role in the diagnosis and early detection of cervical incompetence. Elastography is a relatively new technique, which investigates into another important factor for cervical insufficiency which is "tissue stiffness". The process of early cervical ripening, which is an important and main step in spontaneous preterm delivery, precedes cervical shortening and renders the human cervix soft which can be diagnosed through the color-coding method of the sonoelastography technique. The aim of this study is to determine the value of cervical elastography as a predictor of spontaneous preterm labor and validate the role of strain ratio in such technique.

Results In our study, we examined the pregnant females by transvaginal conventional B-mode ultrasound and complementary elastography technique and recorded the elastography index of their cervix, internal os and external os together with measuring the amount of strain and strain ratio at internal and external os.

Conclusions We concluded that women who had preterm delivery did have higher strain and elastography index as their services were softer than those who had full-term deliveries. Elastography therefore can be a reliable method for the prediction of preterm delivery.

Keywords Cervical strain, Preterm delivery, Elastography, Strain ratio

Background

The cervix is integral to conception, maintenance of pregnancy, and timely delivery of the fetus [1]. The competent human cervix is a complex organ that undergoes extensive changes throughout gestation and parturition. A complex remodeling process of the cervix occurs during gestation, involving timed biochemical cascades, interactions between the extracellular and cellular compartments, as well as cervical stromal infiltration by inflammatory cells. Any disarray in this timed interaction could result in early cervical ripening, cervical insufficiency, and preterm delivery [2]. Preterm delivery (PTD) is defined as birth occurring fewer than 37 complete weeks of gestational age and is responsible for 75% of all neonate deaths. Premature babies are at a higher risk for cerebral palsy, delayed development, and hearing and sight problems. New approaches to detect and treat PTD could decrease 35% of neonatal deaths. Existing methods

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to evaluate the risk of PTD include clinical examination, modified Bishop score calculation, and the cervical length (CL) measured by ultrasound (US) [3]. US elastography is an imaging technique that can visualize the change in the stiffness of an examined cervix and identify cervical tissue inhomogeneity and seem to be a promising approach to predict PTD [2 and 4]. Elastography measures the percentage of tissue deformation that occurs when oscillatory compression is applied.The degree of tissue deformation can be expressed as strain. Increased strain reflects increased deformation (therefore, softer tissue), while decreasing strain reflects reduced deformation (therefore, stiffer tissue) [3]. *Aim of the work* To determine the value of cervical elastography as a predictor of spontaneous preterm labor and validate the role of strain ratio in such technique. In case it would give a clue for patients who are candidate for cervical cerclage operation or supportive progesterone therapy, that all aim to prevent preterm delivery and avoid its consequences.

Methods

Patients The present study is a prospective study included 74 pregnant females, selected from Obstetric outpatient clinics, between 11 and 13 weeks of gestation, initially divided into two groups: 1. low-risk group (Group A): pregnant female at the aforementioned gestational age with no prior history of preterm delivery. 2. high-risk group (Group B): pregnant female at the same GA with history of preterm delivery attributed to cervical factors (incompetence).

Exclusion criteria were Twin pregnancy, pregnant females beyond 14 weeks and history of preterm delivery due to other causes rather than cervical incompetence. Elastography trans-vaginal ultrasound was performed following conventional trans-vaginal ultrasound to evaluate its possible impact on accurate diagnosis and consequent guidance for management planning of cervical incompetence. This study was performed at our university hospital in the period from April 2018 to October 2021. *Image Analysis* Imaging analysis including ultrasound performance (gray-scale and elastographic ultrasound) was performed under the guidance of two qualified consultants of radiology; M.D certified Figs. 1, 2, 3, 4, 5, 6.

Ultrasound examination All patients were examined with B-mode ultrasound. Examinations were performed using a Canon Aplio a 550 that includes a transvaginal probe operating at 7.5–12 MHz software and a combined autocorrelation method. For all patients, the ultrasound examination started with conventional gray-scale ultrasound. The positioning of the patients for imaging was lithotomy that is the patient was lying in the supine with hips and knees flexed 90 degrees to the hips. The scanning protocol included longitudinal imaging the entire cervix and transverse rotation at the level of internal os and external os. A split-screen imaging mode (twin images) was used for conventional US and US elastography so as to obtain identical images optimal for accurate application for region of interest (ROI) and strain ratio (SR) measurement later on. On B-mode sonography, entire cervix was evaluated regarding its length and the presence of funneling. All patients were examined with ultrasound elastography. Sonoelastographic images were obtained by inserting the transducer trans-vaginally, and then, longitudinal section of the entire cervix is focused upon firstly then rotation in transverse section to focus upon rounded section of the internal os and external os. After activating the sono-elastographic function, the following were obtained: elastography index (color coding) of: The entire cervix in longitudinal section, the internal os and the external os in transverse section on a scale from 0 to 4 to be as follows: 0 (blue) is hard, 1(blue to green) is mildly soft, 2 (green to yellow) is moderately soft, 3 (yellow to red) is very soft, and lastly 4 (red) is the softest.

Strain value and strain ratio Applying repeated compression and decompression in a sustained frequency, color coding is superimposed on the translucent B-mode images. To get a correct sono-elastographic map, the process was repeated until a stable image was obtained at the following ROI (region of interest); at the internal os and external os on longitudinal view. And the following are calculated; 1. strain at T1 with T1 being the internal os 2. Strain at T2 with T2 being the external os 3. Strain ratio at T1 and T2 with the numerator in each one, respectively, is the strain at internal os and strain at external os; the denominator is the selected reference area of the relatively harder tissue of the cervical body for ratio calculation. Images then were obtained and saved on a PACS system for viewing. The area considered as the reference for the obtained ratios was a part of the cervical tissue that is away of the cervical canal/gland and any detected cervical fluid within, no vascular structure within and displays a blue or near blue color coding. The ratios and values obtained for the low-risk group of patients were eventually compared to those of high-risk group.

Statistical analysis Statistical analysis was conducted using SPSS 22nd edition, numeric variables were presented in mean ± standard deviation, means were compared using Mann–Whitney U test after normality testing. Categorical variables were presented in frequency and percentages; it was compared using Chi-square test. Cutoff values for elastography indices, sensitivity, and specificity were assessed using ROC analysis. p value < 0.05 was considered significant.

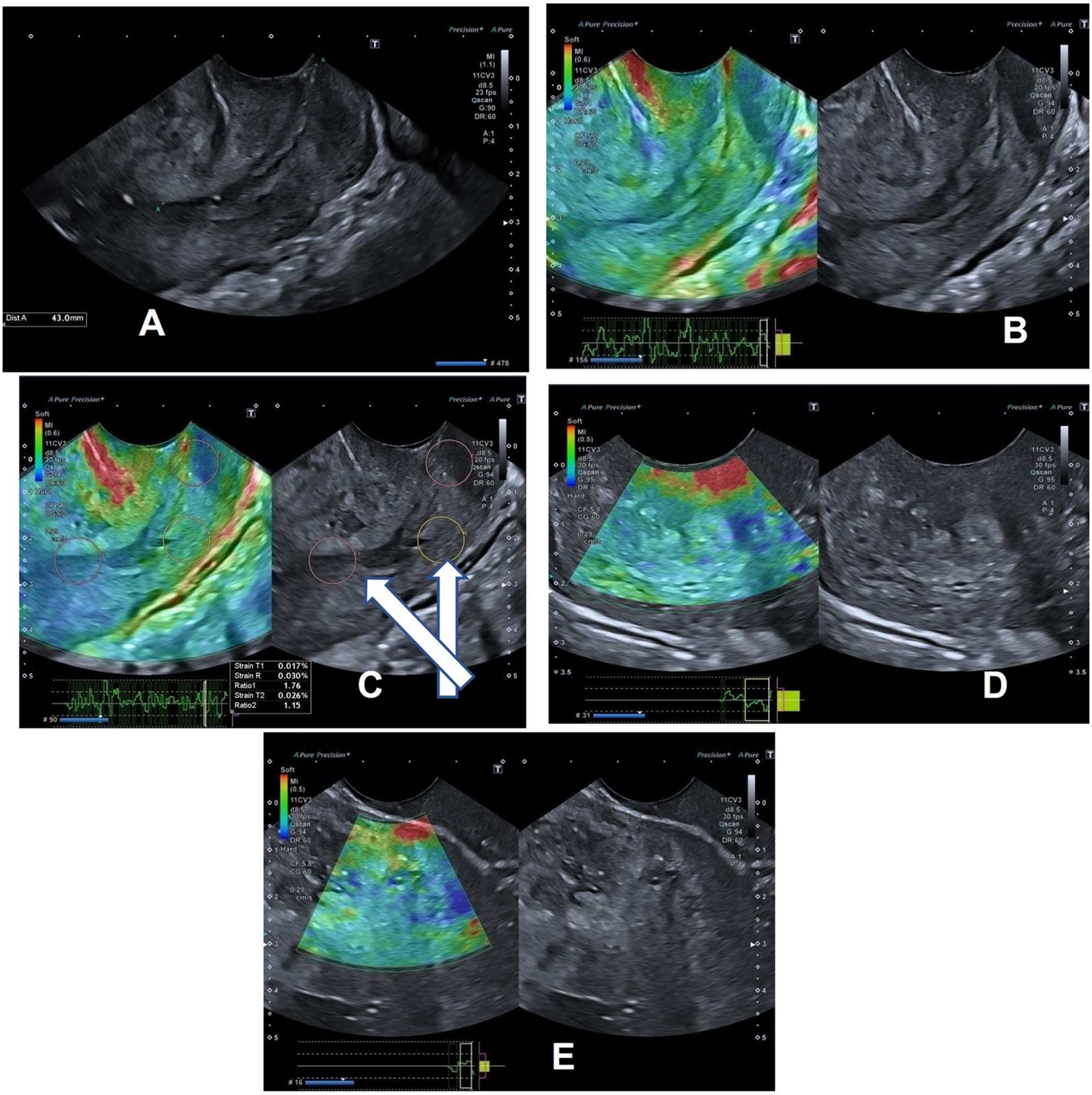

Fig. 1 25-year-old, primigravida. Included in the low-risk group on her first visit (12wks) **A** transvaginal b-mode US showing cervical length 4.3 cm **B** EI at whole cervix [1] mildly soft **C** strain at internal os and external os;0.017 and 0.026, respectively (arrows). **D** EI at internal os [1] mildly soft **E** EI at external os [2] moderately soft

Results

A total of 74 pregnant females were included in our final analysis; they had a mean age of 27.1 ± SD 6.2 years old. Tables 1, 2, 3, 4 show demographics of included patients during first and second visits. First visit at 11 to 14 wks gestation, while second visit was between 20 and 24wks gestation.

Comparison between 74 females sorted as 2 groups: 36 included in low-risk group and 38 included in high-risk group upon two visits based on difference between the cervical length, the strain T1, strain T2, strain ratio T1, strain ratio T2, elastography index (color coding) of the entire cervix, elastography index at T1 and elastography index at T2 and their relation to rather delivering

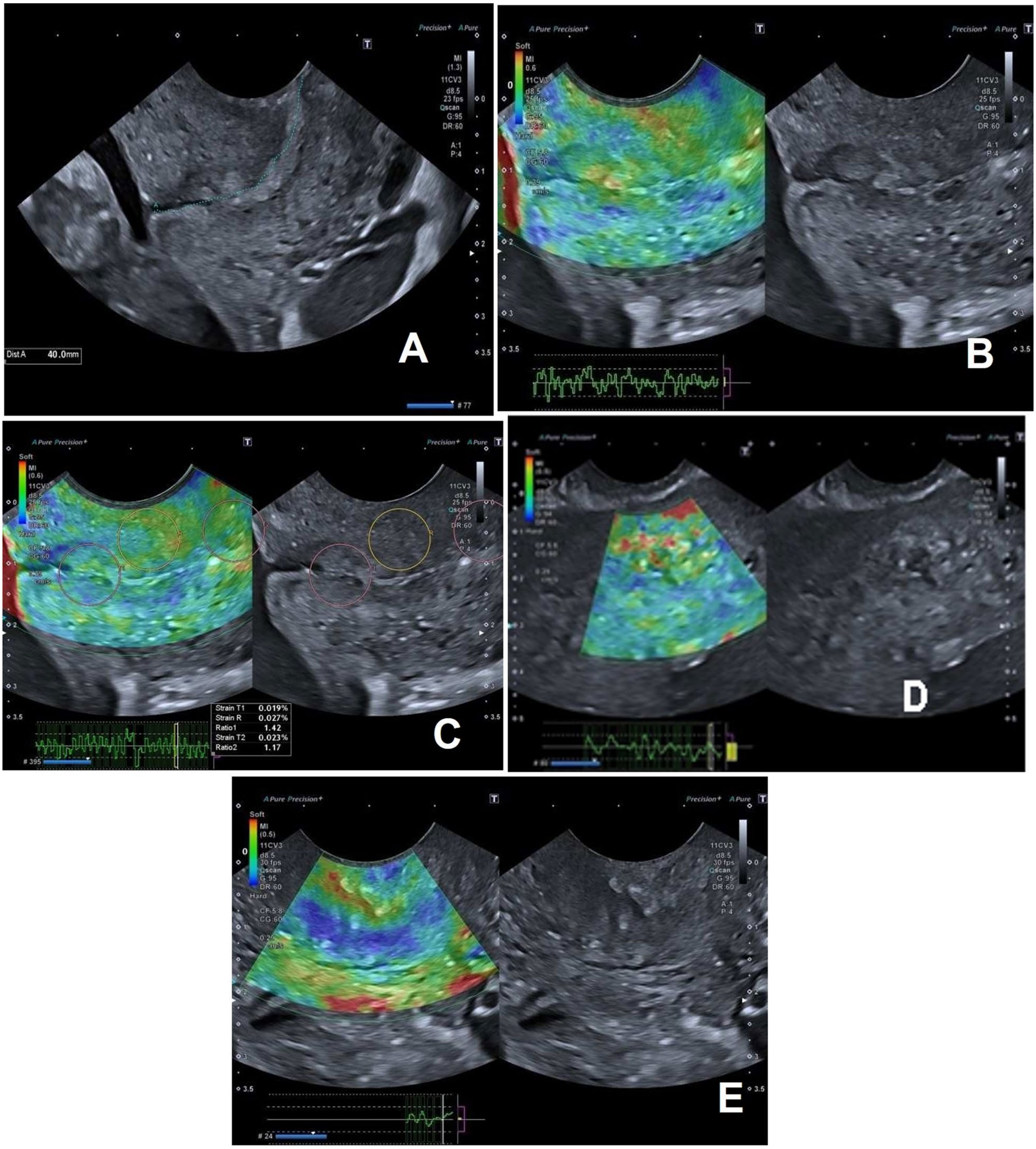

Fig. 2 Same case shown in Fig. 1 Upon her 2nd visit (23 wks.): **A** cervical length 4 cm **B** EI of the whole cervix 2 (moderately soft). **C** strain at internal os and external os doesn't show significant ascend to be as follow 0.019 and 0.023. **D** EI at internal os progressed to 2 (moderately soft) **E** EI at external os still 2 (moderately soft). Upon following-up the patient, she delivered her fetus 39 weeks 2 days

at preterm or full term, with T1 being the internal os and T2 being the external os.

During the first visit, comparison between groups based on term of delivery showed that there was a statistically significant difference of cervical length between the two groups; females with preterm deliveries had a significantly shorter cervix with *p* value 0.0001 and the mean cervical length is 3.2 cm and those delivered term is 4 cm.

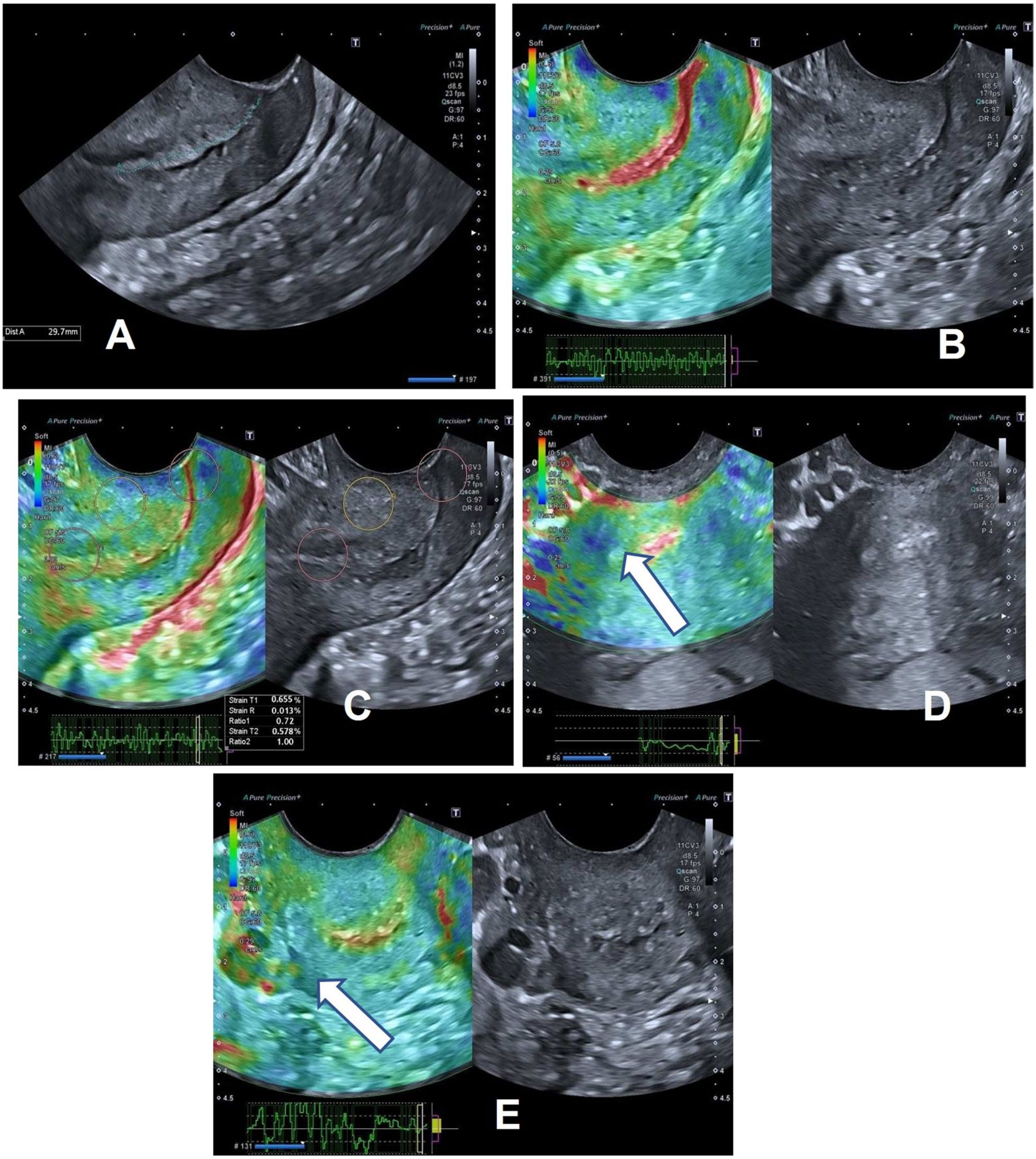

Fig. 3 27-year-old female, with history of previous two preterm deliveries, included in the high-risk group. Upon her 1st visit (11wks), the following data were conducted **A** cervical length 2.9 cm. **B** EI of the whole cervix is 2 (moderately soft). **C** strain at internal os and external os are recorded to be high; 0.655 and 0.578, respectively. **D** EI of internal os is 2 (moderately soft, arrow). **E** EI of external os is 2 (moderately soft, arrow)

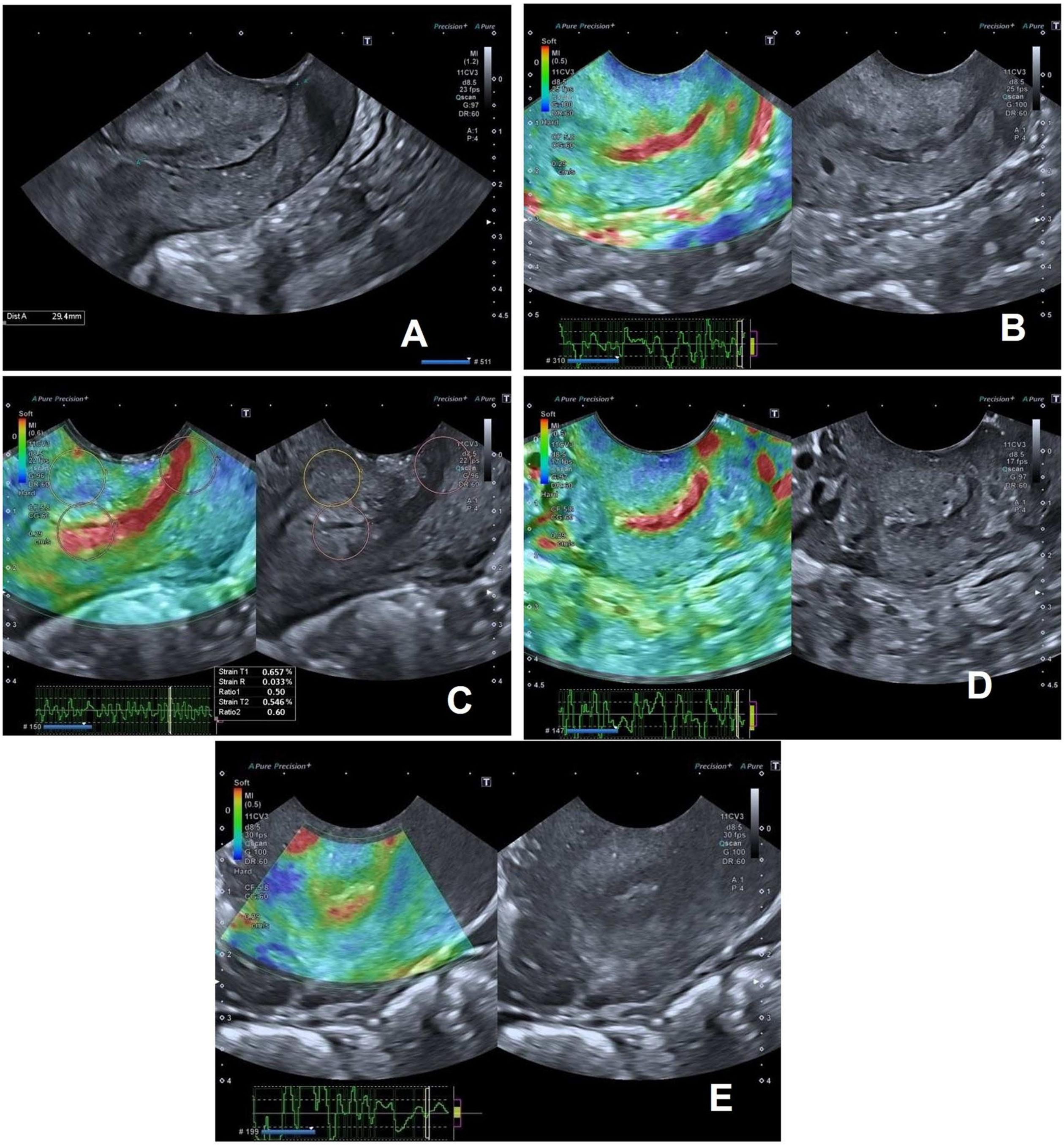

Fig. 4 Same case as in Fig. 3; upon her second visit (24wks), the following data were conducted **A**cervical length 2.9 cm **B** EI of the whole cervix is still 2 (moderately soft). **C** strain at the internal os and external os are still noted to be high 0.657 and 0.546, respectively. **D** EI of the internal os is upgraded to 3 (very soft). **E** EI of the external os is 2 (moderately soft). Upon following up the patient, she delivered her fetus at 31 weeks 2 days

Strain T1 and Strain T2 showed that higher strains were significantly associated with preterm labor with mean strain at T1 = 0.62 in preterm deliveries and mean strain at T1 = 0.16 in term deliveries along with mean strain T2 = 0.56 in preterm deliveries and 0.16 in term deliveries with p values 0.0001 and 0.0001. Strain ratios T1 and T2 were not significantly different between the two groups with p values 0.99 and 0.88, respectively. Table 5.

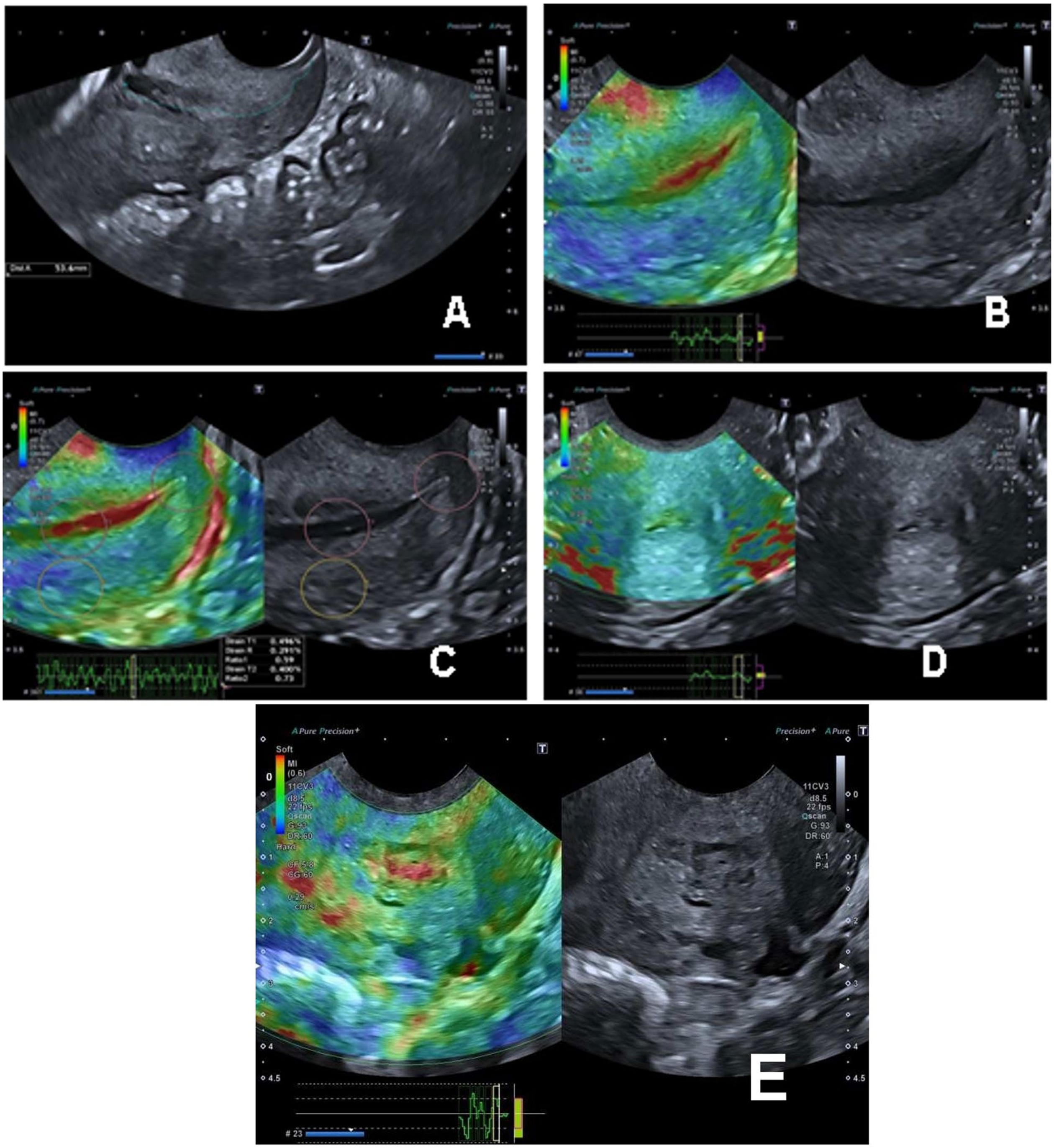

Fig. 5 35-year-old female, no history of preterm delivery, included in the low-risk group. Upon her 1st visit (12 Wks.) the following data were conducted: **A** cervical length is 5.1 cm **B** EI of the whole cervix is 2 predominately with noted areas of index 4 being (moderately soft). **C** strain at internal os and external os is higher than expected to be 0.496 and 0.400, respectively. **D** EI of the internal os is 1 (mildly soft). **E** EI of the external os is 2 (moderately soft)

Elastography index of the entire cervix showed that softer cervices were significantly associated with incidence of preterm labor with p value 0.0001: 30 females delivered preterm; their elastography index being as follows: 1 has mildly soft cervix, 9 have moderately soft cervix and 20 having very soft cervix. Forty-four females delivered as term their elastography index being as follows: 33 mild soft cervix, 8 moderately soft and 3 very soft.

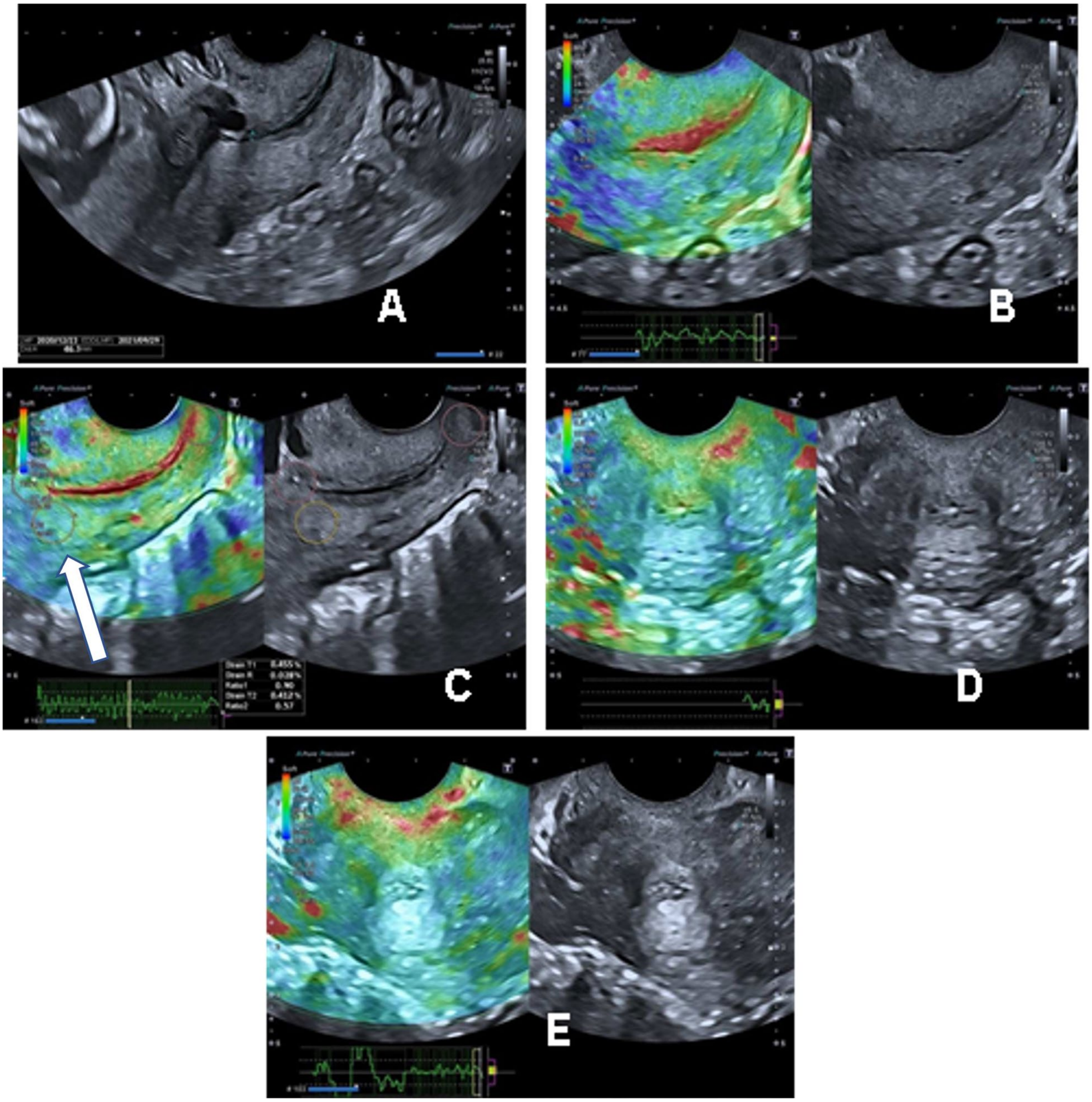

Fig. 6 same case in Fig. 5: Upon her 2nd visit (24 Wks.) the following data were conducted. **A** cervical length is 4.8 cm. **B** EI of the whole cervix is still 2 and giving the same color shades. (moderately soft). **C** strain at internal and external os still high to be 0.455 and 0.412, respectively (arrow). **D** EI of the internal os still predominately 1 with areas of index 2 noted but still (mildly soft). **E** EI of the external os still 1 (mildly soft). Upon following up this patient although showing results similar to those who experienced spontaneous preterm delivery yet she delivered her fetus at 38 weeks gestation; false-positive results

Also, elastography index of the internal os was significantly softer among females who had preterm deliveries with p value 0.0001 with their elastography index of the 30 preterm deliveries being as follows: 1 mildly soft, 17 moderately soft and 12 very soft internal os. On the other hand, 44 females whom delivered full-term their elastography index was as follows: 28 mildly soft, 13 moderately soft and only 3 very soft internal os.

In the second visit, comparison of cervical length showed that preterm deliveries were associated with significantly shorter cervix with *p* value 0.0001 and mean length 3 cm compared to mean length 3.8 cm in full-term pregnancies. T1 and T2 strains were significantly higher

Table 1 Demographics, parity and risk for preterm delivery among the included females

	Count	Column *N* %
Age (mean ± SD)	27.1	6.2
Parity		
Primigravida	6	8.1%
Multipara	68	91.9%
Risk		
Low risk	36	48.6%
High risk	38	51.4%

among preterm deliveries with *p* value 0.0001 and 0.005, respectively, with mean value of 0.77 and 0.50. Table 6.

Elastography index was significantly softer among preterm deliveries with *p* values of 0.0001, along with elastography index of internal and external os, which showed that preterm labors were significantly associated with softer cervix with *p* values of 0.0001 and 0.002, respectively. Thirty females delivered preterm with their elastography index for the whole cervix as follows: 14 moderately soft and 16 very soft, for the internal os as follows: 1 mildly soft, 1 moderately soft and 28 very soft and for the external os as follows: 7 mildly soft, 22 moderately soft and 1 very soft. As compared to 44 females delivered at full term with their elastography index of their entire cervix being as follows: 17 mildly soft, 15 moderately soft and 12 very soft, for the internal os as follows: 17 mildly soft, 27 moderately soft and eventually for the external os; 28 mildly soft and 16 moderately soft.

Comparison of elastography findings during the first visit based on parity showed that primigravida had a significantly higher cervical length with *p* value 0.026 compared to the multigravida with mean cervical length 4.2 cm of the primigravida and mean cervical length of 3.6 cm for the multigravida. While significantly higher strains T1 and T2 were noted among multigravida females compared to the primigravida with p value of T1 0.008 and T2 0.005 and mean value of T1 0.38 and T2 0.35 in multigravida and mean value of T1 0.16 and T2 0.29 in primigravida. Table 7.

During the second visit, strain T1 was significantly higher among multigravida females with *p* value of 0.009 and mean value of 0.46 compared to mean value of 0.09 for the primigravida; strain ratio T1 was significantly lower among multiparas with *p* value of 0.009 and mean value of 0.90 compared to the primigravida who had mean value 1.29 Table 8.

Table 2 Elastography findings of the first visits for the included females

		Mean (in cm)	SD
Cervical length First visit (mean ± SD)		3.69	0.65
Strain T1 First visit (mean ± SD)		0.35	0.34
Strain T2 First visit (mean ± SD)		0.33	0.32
Ratio T1 First visit (mean ± SD)		0.97	0.43
Ratio T2 First visit (mean ± SD)		0.81	0.35
		Count	**N (%)**
E.I entire cervix First visit	Hard	0	0.0
	Mild soft	34	45.9
	Moderate soft	17	23.0
	Very soft	23	31.1
	The softest	0	0.0
E.I Int os First visit	Hard	0	0.0
	Mild soft	29	39.2
	Moderate soft	30	40.5
	Very soft	15	20.3
	The softest	0	0.0
E.I Ex Os First visit	Hard	0	0.0
	Mild soft	47	63.5
	Moderate soft	26	35.1
	Very soft	1	1.4
	The softest	0	0.0

Table 3 Elastography findings of the second visit for the included females

		Mean (in cm)	SD
Cervix length second visit (mean ± SD)		3.47	0.54
Strain T1 second visit (mean ± SD)		0.44	0.37
Strain T2 second visit (mean ± SD)		0.40	0.29
Ratio T1 second visit (mean ± SD)		0.93	0.34
Ratio T2 second visit (mean ± SD)		0.79	0.27
		Count	***N* (%)**
E.I entire cervix second visit	Hard	0	0.0
	Mild soft	17	23.0
	Moderate soft	29	39.2
	Very soft	28	37.8
	The softest	0	0.0
E.I Int os second visit	Hard	0	0.0
	Mild soft	18	24.3
	Moderate soft	28	37.8
	Very soft	27	36.5
	The softest	0	0.0
E.I Ex os second visit	Hard	0	0.0
	Mild soft	35	47.3
	Moderate soft	38	51.4
	Very soft	1	1.4
	The softest	0	0.0

Sensitivity analysis

During the first visit, sensitivity analysis showed that strain T1 significantly predicted the incidence of preterm labor among included females with cutoff of 0.15, sensitivity of 93.3%, specificity of 59.1%, p value of 0.0001 and AUC of 89.9%. Strain T2 significantly predicted the incidence of preterm labor among included females with cutoff of 0.1, sensitivity of 100%, specificity of 61.4%, p value of 0.0001 and AUC of 88.2%. Table 9.

During the second visit, strain T1 significantly predicted the incidence of preterm labor using the cutoff value of > 0.18, sensitivity of 96.7%, specificity of 50%, AUC of 93.7% and p value of 0.0001. Strain T2 significantly predicted the incidence of preterm labor using the cutoff value of > 0.14, sensitivity of 100%, specificity of 43.2%, AUC of 69.5% and p value of 0.005. Table 10.

Table 4 Timing of delivery of the delivered fetuses

		Count	Column *N* (%)
Delivery			
	Full term	44	59.5
	Preterm	30	40.5

Discussion

Preterm delivery is recognized as premature birth of a fetus before 37 weeks of gestation age [4]. It is responsible for 75% of all neonatal deaths [5]. Although there are growing efforts in decreasing the rate of preterm birth, WHO estimated that 11.1% of all births were preterm [6].

The main challenge in preterm delivery is to identify patients with high risk for preterm birth and to prolong the pregnancy as possible during the period between the 23 and 32 weeks, as the mortality and morbidity rates decrease markedly [7].

Elastography is an ultrasound-based imaging technique visualizing the stiffness of examined region. The technique is based on the phenomenon that after applying pressure with the probe, soft tissues are compressed in a greater extent than hard tissues and the gradient values of strain are visualized on a color map [8].

There is cumulating evidence on the usage of elastography in obstetrics and gynecology; studies had investigated the prediction of success of induction of labor [9] and differential diagnosis of endometrial pathologies [10].

In normal pregnancies, the internal os and cervical canal are hard and allow the pregnancy to continue until term; few studies had investigated the role of ultrasound elastography in assessing the progression of labor via

Table 5 Comparison of elastography findings of the first visit and clinical outcomes

		Delivery				*P* value
		Full term (*n* = 44)		Preterm (*n* = 30)		
		Mean	SD	Mean	SD	
Cervical length (in cm)First visit (mean ± SD)		4.0	0.6	3.2	0.2	0.0001
Strain T1 First visit (mean ± SD)		0.16	0.021	0.62	0.3	0.0001
Strain T2 First visit (mean ± SD)		0.16	0.020	0.56	0.3	0.0001
Ratio T1 First visit (mean ± SD)		0.98	0.45	0.95	0.41	0.99
Ratio T2 First visit (mean ± SD)		0.82	0.36	0.80	0.33	0.88
		Count	**Column *N* (%)**	**Count**	**Column *N* (%)**	***P* value**
E.lentire cervix First visit	Hard	0	0.0	0	0.0	0.0001
	Mild soft	33	75.0	1	3.3	
	Moderate soft	8	18.2	9	30.0	
	Very soft	3	6.8	20	66.7	
	The softest	0	0.0	0	0.0	
E.I Int os First visit	Hard	0	0.0	0	0.0	0.0001
	Mild soft	28	63.6	1	3.3	
	Moderate soft	13	29.5	17	56.7	
	Very soft	3	6.8	12	40.0	
	The softest	0	0.0	0	0.0	
E.I Ex os First visit	Hard	0	0.0	0	0.0	0.09
	Mild soft	32	72.7	15	50.0	
	Moderate soft	12	27.3	14	46.7	
	Very soft	0	0.0	1	3.3	
	The softest	0	0.0	0	0.0	

measuring the length of cervix and hardness of the internal os [11].

In the current study, we aimed to determine the value of the evolving technique of cervical elastography as a predictor of spontaneous preterm labor. We recruited a total of 74 pregnant females in our final analysis. They had a mean age 27.1 ± SD 6.2 years old. Majority of the included females were multipara 91.9% (68 cases) versus 8.1% primigravida [6 cases]. Risk assessment was based on previous preterm labor: 51.4% were classified as high risk for preterm labor (38 cases) and 48.6% as low-risk group (36 cases).

Hernandez-Andrade et al. [4] reported a rate of 21 (11%) females who had a preterm delivery in their study. These rates are believed to be lower than the ones reported in the current study because their studies included females with low risk for preterm and included higher proportion of primigravida females.

In the present study, cervical length in the first visit showed a mean 3.69 ± SD 0.65 cm. During the second visit, cervical length showed a mean 3.47 ± SD0.54 cm. During the first visit, comparison between groups based on term of delivery showed that there was a statistically significant difference of cervical length between groups, as females with preterm deliveries had a significantly shorter cervix with *p* value 0.0001.

These findings are consistent with the study conducted by Hernandez-Andrade et al. [4] who showed that females who had a preterm labor had significantly higher prevalence of cervical length < 25 mm (33% versus 6% in full term delivery). In our study, the cutoff of the cervical length was < 3 cm during the first visit and < 2.9 during the second visit with percent of the preterm deliveries among the included females, 40.5% fetuses were delivered preterm (30 cases), while 59.5% were delivered full term (44 cases).

Strain elastography is based on the measurement of tissue displacement under compression. Compression is usually obtained by a manual force applied via

Table 6 Comparison of elastography findings of the second visit and clinical outcomes

		Delivery				*P* value
		Full term ($n=44$)		Preterm ($n=30$)		
		Mean	SD	Mean	SD	
Cervix length (cm)second visit (mean ± SD)		3.8	0.5	3.0	0.1	0.0001
Strain T1 second visit (mean ± SD)		0.21	0.020	0.77	0.27	0.0001
Strain T2 second visit (mean ± SD)		0.32	0.029	0.50	0.24	0.005
Ratio T1 second visit (mean ± SD)		1.02	0.30	0.81	0.35	0.004
Ratio T2 second visit (mean ± SD)		0.79	0.30	0.80	0.24	0.86
		Count	**Column *N* (%)**	**Count**	**Column *N* (%)**	***P* value**
E.I entire cervix second Visit	Hard	0	0.0	0	0.0	0.0001
	Mild soft	17	38.6	0	0.0	
	Moderate soft	15	34.1	14	46.7	
	Very soft	12	27.3	16	53.3	
	The softest	0	0.0	0	0.0	
E.I Int os second visit	Hard	0	0.0	0	0.0	0.0001
	Mild soft	17	38.6	1	3.3	
	Moderate soft	27	61.4	1	3.3	
	Very soft	0	0.0	28	93.3	
	The softest	0	0.0	0	0.0	
E.I Ex os second visit	Hard	0	0.0	0	0.0	0.002
	Mild soft	28	63.6	7	23.3	
	Moderate soft	16	36.4	22	73.3	
	Very soft	0	0.0	1	3.3	
	The softest	0	0.0	0	0.0	

an ultrasound transvaginal probe or it can be created by physiological cardiovascular processes and breath [12].

Irrespective of the elastographic method used, internal os seemed to be denser than surrounding tissues, thus supporting a popular hypothesis that this anatomical region is crucial for maintaining pregnancy [13].

In the present study, strain T1 which was assessed at the internal os (IO) and strain T2 which was assessed at the external os (Eos) showed that higher strains were significantly associated with preterm labor with p value 0.0001, cutoff 0.01, sensitivity of 93.3%, and specificity of 59.1% for strain T1 and p value 0.0001, cutoff 0.1, sensitivity of 100% and specificity of 61.4% for strain T2.Yet, the calculated strain ratios T1 and T2 were not significantly different between low-risk and high-risk groups with p values 0.99 and 0.88, respectively, especially when measured in early pregnancy.

These findings were consistent with the ones demonstrated by Hernandez-Andrade et al. who stated that the presence of soft tissue in the area of the internal os was associated with increased risk of preterm delivery. However, there were no significant associations between the risk of preterm labor and elastography characteristics of the whole cervix and external os; these findings agree with many studies in the literature as well [3, 14 and 15].

In the current study, elastography index (color coding) of the entire cervix showed that softer cervix was significantly associated with incidence of preterm labor with p value 0.0001; also, elastography index of the internal os and external os was significantly softer among females who had a preterm delivery with p values of 0.0001 and 0.002.

These findings agree with Wozniak et al. who examined a group of women at low risk of preterm labor and also found an association between lesser stiffness of the internal os (red or yellow color) at 18–22 weeks of gestation and the risk of preterm delivery (81.1% for women with soft internal os vs. 1.7% for women with firm internal os) [16].

Comparison of elastography findings during the first visit based on parity showed that primigravida had a significantly longer cervical length with p value of 0.026, with mean cervical length of 4.2 cm of the primigravida and mean cervical length of 3.6 cm for the multigravida. Strains T1 and T2 were significantly higher among multipara females with p values of 0.008 and 0.005. With

Table 7 Comparison of elastography findings of the first visit and parity

		Parity				*P* value
		Primigravida (*n* = 6)		Multipara (*n* = 68)		
		Mean	SD	Mean	SD	
Cervical length(cm) First visit (mean ± SD)		4.2	.5	3.6	0.6	0.026
Strain T1 First visit (mean ± SD)		0.16	0.09	0.38	0.33	0.008
Strain T2 First visit(mean ± SD)		0.29	0.018	0.35	0.31	0.005
Ratio T1 First visit(mean ± SD)		1.03	0.50	0.96	0.43	0.92
Ratio T2 First visit(mean ± SD)		.58	0.23	0.83	0.35	0.053
		Count	Column *N* (%)	Count	Column *N* (%)	*P* value
E.I entire cervix First Visit	Hard	0	0.0	0	0.0	0.12
	Mild soft	5	83.3	29	42.6	
	Moderate soft	1	16.7	16	23.5	
	Very soft	0	0.0	23	33.8	
	The softest	0	0.0	0	0.0	
E.I Int os First visit	Hard	0	0.0	0	0.0	0.06
	Mild soft	5	83.3	24	35.3	
	Moderate soft	1	16.7	29	42.6	
	Very soft	0	0.0	15	22.1	
	The softest	0	0.0	0	0.0	
E.I Ex os First visit	Hard	0	0.0	0	0.0	0.57
	Mild soft	5	83.3	42	61.8	
	Moderate soft	1	16.7	25	36.8	
	Very soft	0	0.0	1	1.5	
	The softest	0	0.0	0	0.0	

mean value of T1 0.38 and T2 0.35 in multigravida and mean value T1 0.16 and T2 0.29 in primigravida, during the first visit, sensitivity analysis showed that strain T1 significantly predicted the incidence of preterm labor among included females with cutoff > 0.01, sensitivity of 93.3%, specificity of 59.1%, *p* value of 0.0001 and AUC 89.9%. Strain T2 significantly predicted the incidence of preterm labor among included females with cutoff > 0.1, sensitivity of 100%, specificity of 61.4%, *p* value of 0.0001 and AUC of 88.2%.

In the present study during the second visit, strain T1 significantly predicted the incidence of preterm labor using the cutoff value > 0.18, sensitivity of 96.7%, specificity of 50%, AUC of 93.7% and *p* value of 0.0001. Strain T2 significantly predicted the incidence of preterm labor using the cut off value > 0.14, sensitivity of 100%, specificity of 43.2%, AUC of 69.5% and p value of 0.005.

These findings were similar to the ones reported by Wozniak et al. [16] who found a cutoff value for prediction of preterm labor > 0.14, sensitivity of 84% and specificity of 80%. The same results were reported in a recent meta-analysis, which found that cervical elastography showed a summary sensitivity of 84% (95% CI 0.68, 0.93) and specificity of 82% (95% CI 0.63, 0.93), as well as a recalculated sensitivity of 81% (95% CI 0.64, 0.92) and specificity of 88% (95% CI 0.78, 0.94), to predict preterm labor, AUC of 0.90 (95% CI 0.87–0.93), indicating that cervical elastography is useful to predict preterm labor. Compared with CL measurement, which showed an AUC of 0.60 (95% CI 0.56–0.64), cervical elastography is likely a better choice to predict preterm delivery [2].

To sum up We found that indicators of preterm labor include cervical length, strain T1 and strain T2 measured at both internal and external os, respectively. Elastography index (color coding) is a reliable tool in assessment of cervical stiffness and can significantly predict the incidence of preterm labor. Strain ratio T1 (measures at the internal os) is a good predictor of preterm labor when measured at the second visit (20–24 wks. gestation).

Both strain ratios T1 and T2 (measured at the internal and external os, respectively) show no significant difference between preterm and full-term delivery when measured in early pregnancy (11–13 wks. of gestation). There is no statistically significant difference between primi and multipara in terms of elastography

Table 8 Comparison of elastography findings of the second visit and parity

		Parity				*P* value
		Primigravida (*n* = 6)		Multipara (*n* = 68)		
		Mean	SD	Mean	SD	
Cervix length (cm)second visit(mean ± SD)		3.9	0.5	3.4	0.5	0.067
Strain T1 second visit(mean ± SD)		0.09	0.012	0.46	0.36	0.009
Strain T2 second visit(mean ± SD)		0.021	0.022	0.41	0.29	0.08
Ratio T1 second visit(mean ± SD)		1.29	0.27	0.90	0.33	0.009
Ratio T2 second visit(mean ± SD)		0.84	0.25	0.79	0.28	0.64
		Count	Column *N* (%)	Count	Column *N* (%)	*p* value
E.I entire cervix second visit	Hard	0	0.0	0	0.0	0.13
	Mild soft	2	33.3	15	22.1	
	Moderate soft	4	66.7	25	36.8	
	Very soft	0	0.0	28	41.2	
	The softest	0	0.0	0	0.0	
E.I Int os second visit	Hard	0	0.0	0	0.0	0.21
	Mild soft	3	50.0	15	22.1	
	Moderate soft	3	50.0	25	36.8	
	Very soft	0	0.0	27	39.7	
	The softest	0	0.0	1	1.5	
E.I Ex os second visit	Hard	0	0.0	0	0.0	0.95
	Mild soft	3	50.0	32	47.1	
	Moderate soft	3	50.0	35	51.5	
	Very soft	0	0.0	1	1.5	
	The softest	0	0.0	0	0.0	

Table 9 Sensitivity analysis showing the predictability of elastography findings of the first visit to preterm labor

Test result variable(s)	AUC	*p* value	Cutoff	Sensitivity (%)	Specificity (%)	95% Confidence interval	
Cervical length First visit	0.11	0.0001	3	66.7	6.8	0.034	0.186
Strain T1 First visit	0.898	0.0001	> 0.01	93.3	59.1	0.828	0.969
Strain T2 First visit	0.882	0.0001	> 0.1	100	61.4	0.808	0.955
Ratio T1 First visit	0.500	0.996	> 0.88	50	45.5	0.366	0.633
Ratio T2 First visit	0.490	0.886	> 0.79	63.3	45.5	0.356	0.624

index of the entire cervix and both internal and external os (regarding parity). We found that regarding parity a multigravida showed a significantly higher strain T1 and T2 where T1 is strain measured at the internal os and T2 measured at the external os with *p* values of 0.008 and 0.005, respectively.

Limitations of this study

Small sample size. Most of our cases (90% included sample) were multipara patients who have relatively softer cervix and higher collagen, mucus contents and small amount of fluid distending the canal giving higher elastography indices lowering the specificity in such case.

Strain ratio is calculated by the displacement of cervix versus displacement of normal tissue; in the current study, we calculated the displacement of internal os and

Table 10 Sensitivity analysis showing the predictability of elastography findings of the second visit to preterm labor

Test result variable(s)	AUC	*p* value	Cutoff	Sensitivity (%)	Specificity (%)	95% confidence interval	
Cervix length second visit	0.075	0.0001	< 2.9	96.7	50	0.017	0.133
Strain T1 second visit	0.937	0.0001	> 0.18	96.7	50	0.882	0.992
Strain T2 second visit	0.695	0.005	> 0.14	100	43.2	0.576	0.813
Ratio T1 second visit	0.302	0.004	> 0.65	66.7	9.1	0.177	0.426
Ratio T2 second visit	0.511	0.869	> 0.46	90	13.6	0.379	0.644

external os versus harder cervical body, which might not be standard for ratio calculation.

Ultrasound—in general—is an operator dependent tool, which renders reproducibility of results a matter of question; however, this can be overcome by having one operator for all cases.

Conclusion

We concluded that women who had preterm delivery did have higher strain and elastography index as their cervices were softer than those who had full-term deliveries. Elastography therefore can be a reliable method for the prediction of preterm delivery.

Abbreviations

CL	Cervical length
CI	confidence Interval
Eos	External os
EI	Elastography index
Int os	Internal os
PACS	Picture archive and communicating system
PTD	Preterm delivery
ROI	Region of interest
SD	Standard deviation
SE	Strain elastography

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Author contributions
Equal sharing in data collection and analysis, manuscript writing and editing by the four authors. RH and YE did the initial manuscript writing and data analysis. YH was assigned to data collection and technique. HG shared in writing, editing and revising data and manuscript. All authors have read and approved the final manuscript.

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Declarations

Ethics approval and consent to participate
The study protocol was approved by the Local Ethics Committee. Vancouver ethical standards were followed in the conduct of the study. No available ethics' committee Reference number. All patients signed a written consent to perform the procedure.

Consent for publication
All patients included in this research gave written informed consent to publish the data contained and/or analyzed within this study.

Competing Interests
The authors declare they have no competing interests.

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