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The significance of ultrasound parameters and clinical factors in predicting successful labor induction among nulliparous women

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ABSTRACT

Objectives: To compare the values of ultrasound and clinical parameters for predicting outcomes of induction of labor (IOL) among healthy nulliparous women with a singleton, term cephalic pregnancy.

Methods: The cervical length, cervical strain elastography, posterior cervical angle, head-perineum distance, Bishop score, and maternal parameters were assessed before IOL with a combined method—Foley catheter and Misoprostol perorally. The main outcome was vaginal delivery.

Results: Variation in cervical tissue elasticity, represented by elasticity index (E), was significantly different between outcome groups—vaginal delivery and cesarean section (CS) in internal os, in the anterior lip near the cervical canal and the midpoint of the anterior and posterior lip ($p < 0.05$). The E was higher—softer in the vaginal delivery group. The overall elasticity was significantly higher in the middle part of the cervix in the vaginal delivery group. However, other ultrasound metrics did not differ significantly across the outcome groups. Overall, women who delivered vaginally were taller and had a lower pre-pregnancy BMI ($p = 0.02$ for both variables). Univariate and multivariate analyses showed maternal height was the significant independent predictor of CS (AOR 0.91, 95% CI 0.84–0.98). The prognostic value for vaginal delivery, based on cervical length, maternal height, Bishop score, and parameters of cervical strain elastography, was poor (AUC < 0.7).

Conclusion: The study underscores the importance of cervical tissue elasticity in predicting vaginal delivery outcomes, while also highlighting that maternal height is a significant independent predictor of cesarean delivery. However, evaluated metrics in the study have limited prognostic value for predicting vaginal delivery. This suggests a need for further research to identify more reliable predictors of delivery outcomes.

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Nulliparous; labor induction; cervical elastography; strain elastography; cervical length

1. Introduction

The global prevalence of induction of labor (IOL) has increased significantly in recent decades, driven by the primary goal of reducing adverse neonatal and maternal outcomes, particularly the risk of fetal death [1,2]. However, this increase in IOL has introduced a complex decision-making process for clinicians, who must weigh the benefits against the associated costs and possible adverse perinatal outcomes. Therefore, there is a need for good prediction tools of IOL outcomes to optimize healthcare system recourses.

Several studies have shown poor Bishop score (BS) reliability [3]. Transvaginal ultrasound provides a better prediction of successful IOL than the BS [4]; however, it cannot be used as a predictive tool for the mode of delivery in nulliparous women before the onset of labor [5]. Instead of using the BS, assessing cervical length *via* ultrasound can reduce the need for prostaglandins for IOL in nulliparous women [6], and the BS is less tolerable than other investigative methods [4,7,8]. Consequently, researchers are seeking an accurate evaluation method before labor induction.

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Many studies, with different degrees of success, have attempted to discover the usefulness of ultrasound parameters such as cervical length, posterior cervical angle, head-to-perineum distance, fetal head position and station, progression angle, and head-to-symphysis distance to predict the success of IOL [9].

Cervical elastography is another potential method for assessing the process of cervical ripening and outcome prediction. Although several publications have shown significant results in anticipating preterm birth using cervical elastography [10,11], its application to prognosticate successful labor induction remains controversial.

Cervical biochemical mediators also contribute to the cervical ripening process. Data show that during induced cervical ripening in nulliparous women, the concentrations of insulin-like growth factor binding protein 1 (IGFBP-1) and phosphorylated insulin-like growth factor binding protein (phIGFBP-1) in the cervix are increased [12].

Considering all factors, our study aims to determine which ultrasound (cervical length, cervical elastography, posterior cervical angle, head-perineum distance) or clinical parameters are best predictors of the outcome of labor induction in healthy nulliparous women with a singleton, term cephalic pregnancy, and an unfavorable cervix, without pregnancy complications or systemic diseases.

2. Materials and methods

2.1. Study design and participants

The prospective single-center, single-arm cohort study was conducted from 1 June 2022 to 28 February 2024 at the Riga Maternity Hospital (RMH), a secondary-level monodisciplinary perinatal care hospital in Latvia. More than 30% of all births in Latvia take place in the RMH every year. After written informed consent, 150 nulliparous women with singleton-term pregnancies who underwent IOL were invited to participate in the study. The study was approved by the Research Ethics Committee of Riga Stradins University (No 2-PĒK-4/152/2022), 14.03.2022.

The inclusion criteria were healthy women with a term (≥37 gestational weeks) singleton pregnancy in cephalic presentation, a Bishop score of 6 or less, cervical dilatation of 2 cm or less, and intact membranes.

The exclusion criteria were as follows: patients younger than 18 years, unable to read or understand the consent form in Latvian or Russian, with human immunodeficiency virus (HIV), spontaneous onset of labor, membrane rupture before labor, multiple pregnancies, medical conditions requiring assisted second stage of labor, preeclampsia, HELLP syndrome, fetal growth restriction with an estimated delivery weight (EDW) or abdominal circumference (AC) below the third percentile, small for gestational age (EDW below the tenth percentile) with an abnormal Doppler studies, and fetal antenatal death.

2.2. Examination before IOL

Participants were assessed upon admission for IOL. Before the digital evaluation of BS, women were asked to empty the bladder. A speculum examination was then performed, during which the *Actim® Partus* test (Medix Biochemica, Finland) was conducted using the one-step dipstick provided in the bedside test kit. The *Actim® Partus* test is designed to detect the presence of phIGFBP-1 in cervical or vaginal fluid. The test results were interpreted as either positive or negative.

2.3. Ultrasound measurements

After the test, transvaginal and transperineal ultrasound examination was performed. All ultrasound assessments were performed using the Versana Premier system (GE Medical System, Chicago, IL, USA, convex 2–8 MHz or transvaginal 4–10 MHz probes). Four ultrasound measurements were recorded [1]: cervical length (CL) [2], cervical elastography [3], head-perineum distance (HPD), and [4] posterior cervical angle (PCL).

Elastography software was used to obtain cervical strain elastography.

All recordings were obtained by two authors, L.Ķ. (Level II, routine) and N.V. (Level III, expert), both of whom are certified specialists in cervical assessment (holding the Fetal Medicine Foundation Certificate of Competence in cervical assessment). The recordings were stored for later analysis [13].

Ultrasonography was performed taking into account clinical practice guidelines and recommendations about ultrasound in labor interventions [14]. First, the presenting part, the head, was confirmed by ultrasound. Second, CL was measured by aligning the transvaginal probe with the cervical canal to obtain the midsagittal view. The ultrasound assessment followed the Fetal Medicine Foundation criteria, and the image was optimized by magnifying two-thirds of the cervix before measuring the CL in B-mode [15]. It was calculated as the linear distance between the internal and external os with minimal or no pressure on the cervix along its longitudinal axis, allowing the patient to breathe naturally [15,16] (Figure 1(A)).

Once an optimal image of the cervix is obtained, the software displays a live dual-screen view, with the 2-dimensional (2D) grayscale image at the bottom and the elastography at the top of the screen. The strain value of each region of interest (ROI) was measured using a 5-mm diameter circle placed in the center of each ROI. A six-step scale was developed to describe various parts of the cervix in cervical elastography findings. This scale includes elasticity index (E) in the internal os (E1), the external os (E2), the anterior cervical lip near the cervical canal (CC) (E3), the posterior cervical lip near CC (E4), the midpoint of the anterior lip (E5), and the midpoint of the posterior lip (E6) (Figure 2). The precaution was taken to ensure that no other structures (e.g. vagina, fetal parts, or bladder) are included within the boundaries of the ROI box. Tissue strain values were automatically displayed on the screen. The authors determined the strain values for the anterior and posterior cervical lips by averaging the measurements: (E3+E5)/2 for the anterior lip (E-AL) and (E4+E6)/2 for the posterior lip (E-PL).

The E1/E2 ratio was determined by comparing it with findings from other studies that utilized the ElastoScan program.

The posterior cervical angle was measured as the angle between the midsagittal line along the cervical canal and a line tangential to the posterior uterine wall [9,14] (Figure 1(A)).

A transperineal ultrasound was then performed using a probe covered with a condom and ultrasound gel placed transversely on the patient's perineum. In the sagittal view, the head-perineum (HPD) distance, the shortest distance from the fetal skull's outer bony limit to the perineum's, was measured [9,14,17] (Figure 1(B)).

2.3.1. Reproducibility of elastography

The interclass correlation coefficient (ICC) was used to assess the intra- and interobserver reproducibility of cervical strain elastography was assessed before the study. The cervical strain elastography was performed and video captured for 17 pregnant patients in the third trimester by an ultrasound – expert, while two sonographers each performed four acquisitions and measurements of ROIs on the captured video to determine the intraclass correlations. Intra-rater reliability showed intraclass correlation (ICC) for each ROI was ≥0.77, which indicates good reliability. The ICC for inter-rater reliability for each ROI was ≥0.90.

2.4. Induction protocol

When during vaginal examination, the BS was more than 6 points, the patient was excluded from the study.

Labor was induced using a combined method of the Foley catheter (FC), and misoprostol (Figure 3) according to the hospital protocol for IOL.

The FC 16 F was inserted either digitally or with direct visualization using a speculum. The FC bulb was placed just above the level of the internal os and inflated with 60 ml of sterile liquid – sodium chloride 0.9%. The correct position of the FC was checked by transvaginal ultrasound for all patients. The catheter was adhered to the inner thigh with gentle traction.

The women received 25 microgrammes of misoprostol *per os* every 2 h, repeated up to 5 additional times for 12 h. Misoprostol was stopped when the patients reported regular active uterine contractions, which were defined as three uterine contractions in 10 min, at least for 30 min.

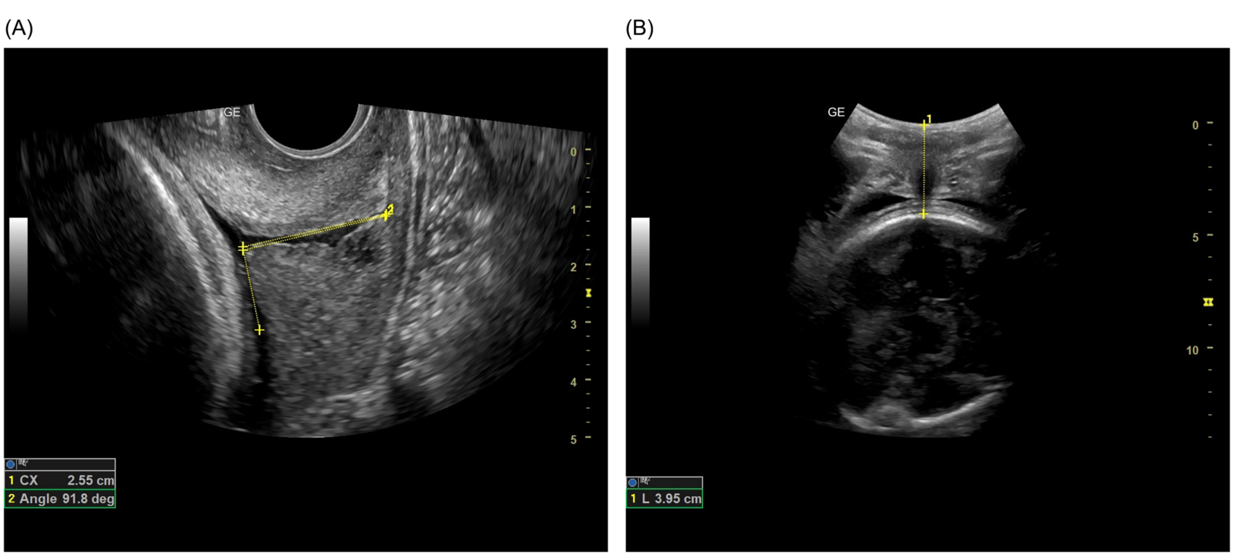

Figure 1. Ultrasound measurements. (A). Transvaginal ultrasound. CX - cervical length (CL). Angle - posterior cervical angle (PCL). (B). Transperineal ultrasound. L - the head-perineum distance (HPD).

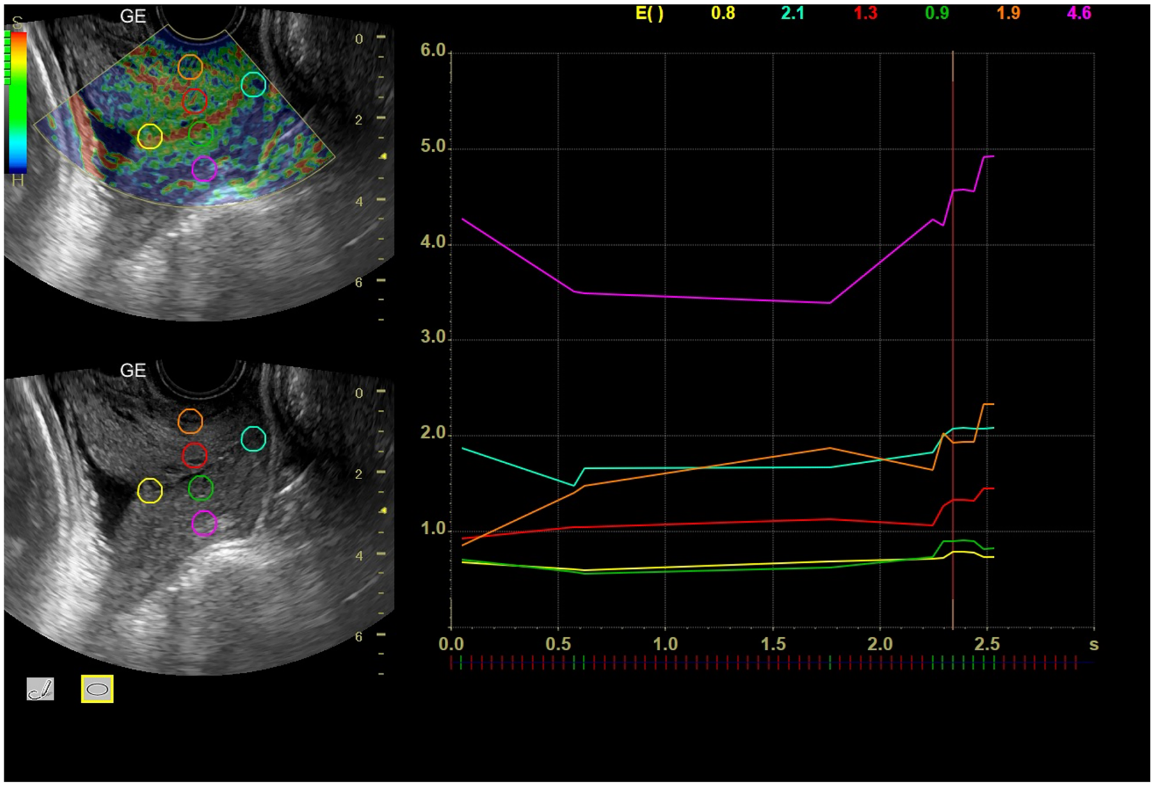

Figure 2. Technical considerations of elastography measurements.
Color map elastography at the top, grey scale at bottom showing ROI. Legend: yellow ring – (E1) ROI on the internal cervical os, blue ring - (E2) ROI on the external cervical os, red ring – (E3) ROI on the anterior cervical lip close to the cervical chanel, green ring - (E4) ROI on the posterior cervical lip close to the cervical chanel, orange ring – (E5) ROI on the middle of anterior lip, violet ring – (E6) ROI on the middle of posterior lip.

The vaginal examination was performed at the onset of regular contractions or in the case of catheter expulsion. If FC was still in place after 12h, the catheter was deflated and removed. If clinically acceptable and cervical dilation was at least 4cm with intact membranes and 2h after the last dose of misoprostol, an amniotomy was performed.

According to our local protocol, we administered oxytocin infusion after 2h of removal of the FC if there were no uterine contractions. Our local protocol is 5 international units of oxytocin in 50ml saline solution, infused at a rate of 3ml/h, without increment during the first hour. If there are no uterine contractions during the first hour, the increments are 3ml every 30min until 3–5 regular painful contractions in 10min are achieved, with a maximum dose of 30ml/h.

If the FC was left in place for more than 13h after the initiation of IOL, the patient was excluded from further study due to a breach of the induction protocol. The success of IOL has defined vaginal delivery and the active phase of labor characterized by active uterine contractions and cervical dilation of at least 5-6cm.

2.5. Maternal characteristics and pregnancy outcome

Maternal demographic characteristics, including age, weight, height, body mass index, method of conception, etc., were recorded securely in an electronic database. Pregnancy results were obtained from maternity and newborn records and recorded in our database.

2.6. Outcomes

The primary outcome of the IOL was whether the mode of delivery - vaginal or by CS. Secondary comparisons assessed the vaginal delivery group against CS at full cervical dilation and CS with non-full cervical dilation. CS due to fetal distress was excluded from analysis in the secondary comparison.

2.7. Statistical analysis

The data were analyzed using the statistical software SPSS (29.0; SPSS Inc., Chicago, IL, USA). $p < 0.05$ was considered statistically significant.

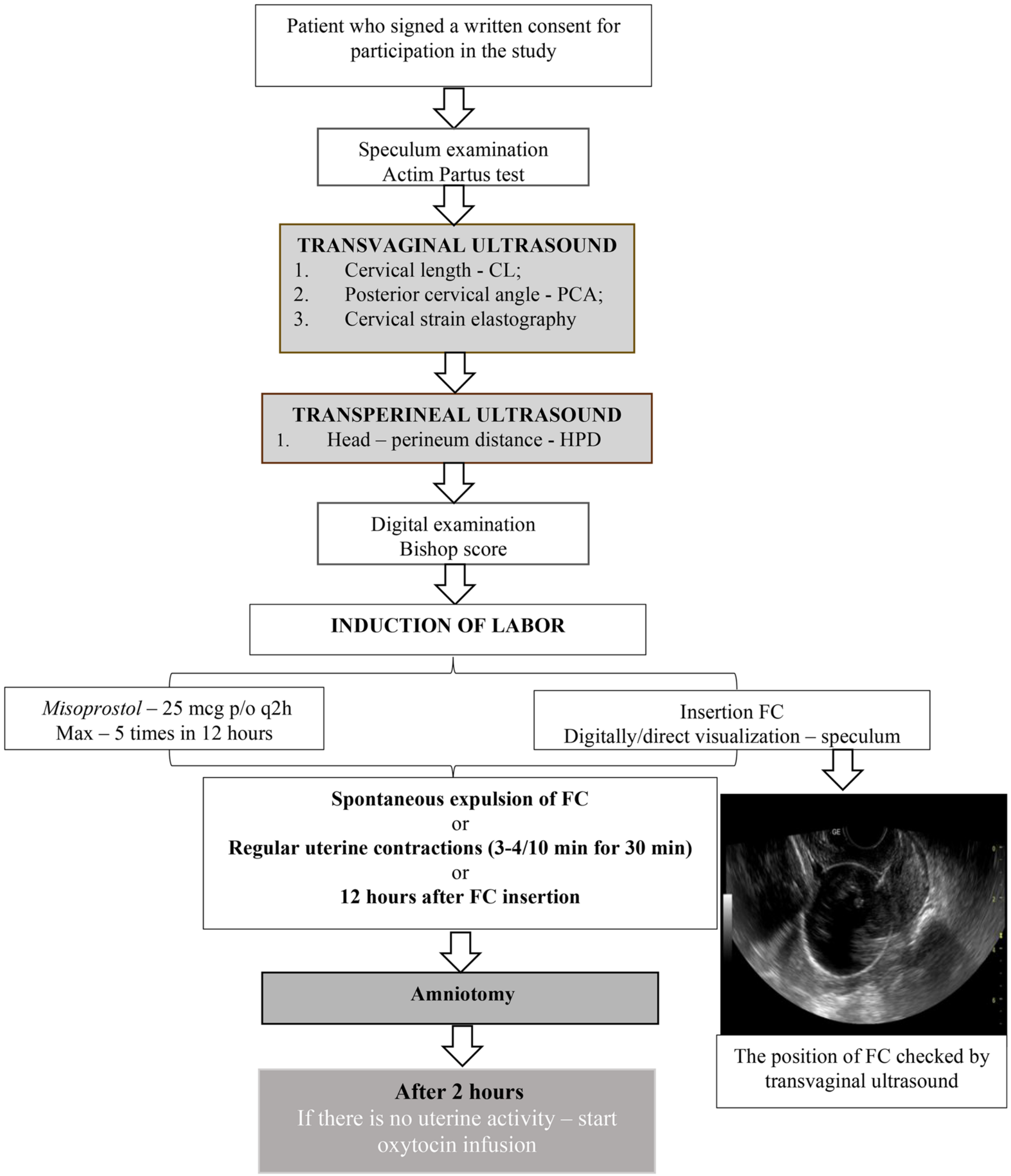

Figure 3. Examination before IOL and induction protocol.

The maternal, newborn, clinical, and ultrasound parameters were compared using the vaginal delivery group as a reference. Parametric data were evaluated for normal distribution using the Kolmogorov-Smirnov test. Descriptive statistics was used (proportions for categorical variables, means (with standard deviations), and medians (with interquartile range) for continuous variables). The Mann–Whitney U or Student's *t*-tests were used for univariate analyses to compare continuous data. As appropriate, chi-square or Fisher's exact tests were used for categorical variables. Multivariate analysis for the detection of independent variables associated with the CS delivery was performed using binary logistic regression analysis.

The predictive value of ultrasound measurements and Bishop for successful vaginal delivery was evaluated using Receiver-Operating Characteristics (ROC) curves. The area under the ROC curve (AUC) and 95% confidence interval (CI) were applied to the predictive value. The value of the area under the curve (AUC) was as follows: >0.9, excellent predictive value; 0.8–0.9, good predictive value; 0.7–0.8 acceptable predictive value; 0.6–0.7, poor predictive value; 0.5–0.6, no predictive value [18].

3. Results

Of 150 women recruited, 14 were excluded: two had early FC expulsion, 10 had FC deflated after over 13 h, one continued misoprostol after FC expulsion, and one had an emergency CS due to umbilical cord prolapse, leaving 136 patients in the study (Figure 4).

The primary indications for IOL included post-term in 74 (54.4%), maternal request in 36 (26.5%), assisted reproductive techniques in 12 (8.8%), prolonged latent phase in seven (5.1%), and other reasons in seven (5.1%) cases.

Following IOL, 112 (82.4%) resulted in vaginal delivery, while 24 (17.6%) required emergency CS. Of the CS, 10 were due to fetal distress, seven were with full cervical dilation, and seven without achieving full dilation. The fetal distress was defined as the presence of changes in fetal cardiotocography that required immediate delivery. The umbilical arterial pH was 7.20 ± 0.10, a base excess −9.03 ± 3.48 mmol/L in the group CS due to fetal distress. The metabolic acidosis (an umbilical arterial pH at birth < 7.10 and/or a base excess > 10 mmol/L) was observed in 3 out of 10 newborns; none were admitted to the newborn intensive care unit.

Table 1 displays the comparison of maternal, fetal, and cervical characteristics (BS) between the vaginal delivery and CS groups. The analysis of these variables revealed no significant differences between the two, except for a shorter time from fetal catheter insertion to the onset of active uterine contractions in the vaginal delivery group ($p = 0.002$), as well as differences in maternal height and pre-pregnancy BMI. Overall, women who delivered vaginally were taller and had a lower pre-pregnancy BMI ($p = 0.02$ for both variables).

There was no significant difference in newborn outcomes between the two groups. In the vaginal delivery group, Apgar score at 1 and 5 min, and newborn intensive care unit admission rates were 8 (IQR 8–8), 9 (IQR 9–9), and 3 (2.7%), respectively, compared to 8 (IQR 8–8; $p = 0.57$), 9 (IQR 9–9; $p = 0.37$), and 0% ($p = 0.99$) in the CS group.

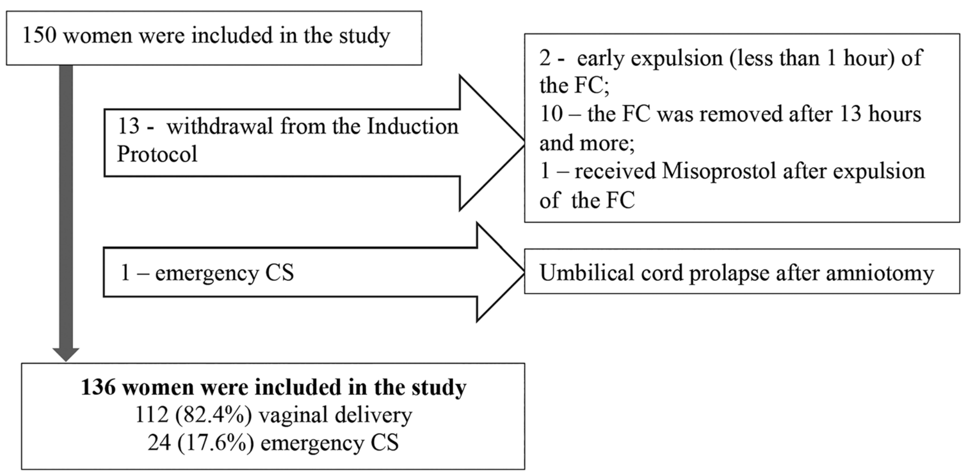

Figure 4. Flow chart showing participation and exclusion in the study.

Table 1. The comparison of maternal and cervical characteristics between the vaginal delivery and CS groups.

Characteristics	Total $n = 136$	Vaginal delivery $n = 112$	CS $n = 24$	p
Maternal age (years), median (IQR)	29 (26–31)	29 (26–31)	30.5 (25.3–34.8)	0.34
Maternal age ≥35 years, *n* (%)	18 (13.2)	12 (10.7)	6 (25.0)	0.09
Maternal height (cm), median (IQR)	169 (164.3–172.0)	170 (165.0–173.0)	166.5 (162.3–170.0)	0.02
Pre-pregnancy BMI (kg/m^2), median (IQR)	22.0 (20.5–24.2)	21.6 (20.2–23.8)	23.6 (921.7–25.5)	0.02
Weight gain during the pregnancy (kg), mean (SD)	15.0 (5.0)	15.0 (4.9)	15.4 (5.5)	0.70
Gestational age (weeks), median (IQR).	41.0 (40.0–41.0)	41.0 (40.0–41.0)	40.0 (39.3–41.0)	0.36
Type of conception, *n* (%)				
Spontaneous	121 (89.0)	101 (90.2)	20 (83.3)	0.30
IVF	15 (11.0)	11 (9.8)	4 (16.7)	
Bishop score before IOL, median (IQR)	4 (3-5)	4 (3-5)	4 (3-6)	0.60
Bishop score difference before FC insertion and after removal, median (IQR)	4 (3-5)	4 (3-5)	5 (4-6)	0.056
Actim®Partus test positive, n (%)	56 (44.1)	45 (43.7)	11 (45.8)	0.85
Birth weight (g), mean (SD)	3671.5 (407.5)	3664.5 (403.8)	3704.4 (431.7)	0.67
Neonatal sex, n (%)				
Female	74 (54.4)	58 (51.8)	16 (66.7)	0.18
Male	62 (45.6)	54 (48.2)	8 (33.3)	
Time from FC insertion to removal (hh:mm), mean (SD)	7:19 (2:27)	7:14 (2:28)	7:39 (2:22)	0.70
Time from FC insertion to active uterine contractions (hh:mm), mean (SD)	7:25 (2:56)	7:15 (2:33)	8:15 (4:27)	0.002
Time from FC insertion to active labor phase (hh:mm), mean (SD)	8:30 (3:21)	8:18 (2:59)	9:34 (4:50)	0.11

Table 2 shows the differences in ultrasound characteristics between the successful and failed outcomes of IOL. Variation in tissue elasticity, represented by the elasticity index, differed significantly between the groups at the internal os (E1), the anterior lip near the cervical canal (E3), and the midpoint of both the anterior (E5) and posterior lips (E6) ($p<0.05$). Overall elasticity was significantly higher in the middle part of the cervix (E-AL; E-PL) in the vaginal delivery group. However, other ultrasound metrics did not differ significantly between the vaginal delivery and CS outcome groups.

Table 3 compares maternal characteristics, perineal and cervical ultrasound measurements between the vaginal delivery group and CS subgroups at full and incomplete dilatation. Almost half of the women who had CS with incomplete cervical dilation were 35 years old or older and had a significantly higher BMI (29.2 (28.7–30.2) vs. 27.0 (25.2–29.5) kg/m^2) compared to women who had a vaginal delivery. Elasticity at the midpoint of the posterior lip was significantly higher in those who achieved full dilation ($p=0.02$).

Univariate and multivariate analyses showed that maternal height was the significant independent predictor of CS (AOR 0.91, 95% CI 0.84–0.98). Cervical length and elastography parameters were not essential determinants (Table 4).

The area under the curve (AUC) for cervical length in predicting successful IOL with vaginal delivery was 0.617 (95% CI 0.486–0.749) (Figure 5(A)), indicating poor diagnostic value.

Similarly, maternal height and BS before IOL also demonstrated weak diagnostic performance, with AUC of 0.624 (95% CI 0.492–0.757) and 0.652 (95% CI 0.538–0.767), respectively (Figure 5(B)). The highest diagnostic effectiveness observed from different parts of the cervix according to strain elastography was in the E3 region—specifically, the anterior cervical lip near the cervical canal—with an AUC of 0.686 (95% CI 0.559–0.813). However, it did not reach an AUC of 0.7 or higher (Figure 5(C)).

Table 2. The difference in ultrasound measurements between the vaginal and CS group.

Characteristics	Vaginal delivery $n=112$	CS $n=24$	p
Cervical length (cm), mean (SD)	2.6 (0.8)	3.0 (1.0)	0.35
Posterior cervical angle – PCA (⁰), mean (SD)	127.5 (19.7)	118.5 (15.3)	0.15
Head-perineum distance, HPD (cm), median (IQR)	4.9 (4.5-5.3)	5.1 (4.6-5.5)	0.13
E1, median (IQR)	2.5 (1.2–3.5)	1.5 (1.1–2.4)	0.03
E2, median (IQR)	1.9 (1.2–2.5)	1.8 (1.0–2.3)	0.53
E3, median (IQR)	1.7 (1.1–3.0)	1.0 (0.7–2.3)	0.004
E4, median (IQR)	2.2 (1.5–3.8)	2.2 (1.2–3.1)	0.22
E5, median (IQR)	1.0 (0.6–2.0)	0.7 (0.4–1.4)	0.08
E6, median (IQR)	3.6 (3.0–4.3)	3.0 (2.1–3.9)	0.02
E-AL, median (IQR)	1.6 (1.1–2.5)	1.0 (0.7–1.5)	0.003
E-PL, median (IQR)	3.0 (2.3–3.9)	2.5 (2.1–3.3)	0.048
E1/E2	1.3 (0.9–1.9)	1.2 (0.8–2.0)	0.51

Discussion

Our study provides unique insights as it is the first, to the authors' knowledge, to compare cervical ultrasound parameters—including elastography—and clinical factors to identify the most sensitive predictor of vaginal birth in healthy nulliparous women with a single-term pregnancy induced by a combined

Table 3. Comparison of maternal and ultrasound characteristics between the vaginal delivery group and CS groups.

		CS at full dilation		non-full dilation CS	
Characteristics	Vaginal delivery $n=112$	$n=7$	p	$n=7$	p
Maternal age ≥35 years, n (%)	12 (10.7)	0 (0)	0.47	3 (42.9)	0.042
Maternal height (cm), median (IQR)	170 (165.0–173.0)	167 (164.0–172.0)	0.38	166 (165.0–170.0)	0.29
BMI at delivery (kg/m2), median (IQR)	27.0 (25.2–29.5)	28.1 (27.9–36.6)	0.09	29.2 (28.7–30.2)	0.02
Obesity at birth (BMI ≥30 kg/m^2)	24 (21.4)	2 (28.6)	0.65	2 (28.6)	0.65
Actim Partus test positive, n (%)	45 (43.7)	2 (28.6)	0.36	3 (42.9)	0.64
Bishop score before IOL, median (IQR)	4.0 (3.0–5.0)	4.0 (1.0–6.0)	0.65	3.0 (2.0–5.0)	0.38
Bishop score difference before FC insertion and after removal, median (IQR)	4.0 (3.0–5.0)	5.0 (4.0–6.0)	0.17	6.0 (4.0–8.0)	0.08
Cervical length (cm), mean (SD)	2.6 (0.8)	2.9 (1.2)	0.20	3.5 (0.9)	0.69
Posterior cervical angle – PCA (0), mean (SD)	127.5 (19.7)	125.3 (22.1)	0.74	112.2 (9.2)	0.07
Head-perineum distance, HPD (cm), median (IQR)	4.9 (4.5–5.3)	5.1(4.9–5.5)	0.18	5.4(4.8–5.9)	0.16
E1, median (IQR)	2.5 (1.2–3.5)	1.8 (1.0–1.8)	0.17	1.9 (1.4–2.8)	0.50
E2, median (IQR)	1.9 (1.2–2.5)	1.5 (0.9–2.8)	0.56	2.0 (1.5–2.5)	0.61
E3, median (IQR)	1.7 (1.1–3.0)	1.0 (0.7–2.7)	0.09	0.9 (0.7–3.5)	0.42
E4, median (IQR)	2.2 (1.5–3.8)	2.1 (1.3–3.0)	0.49	2.6 (1.4–3.4)	0.92
E5, median (IQR)	1.0 (0.6–2.0)	0.6 (0.4–1.4)	0.19	0.8 (0.4–2.1)	0.54
E6, median (IQR)	3.6 (3.0–4.3)	2.9 (1.6–3.0)	0.02	4.0 (3.5–4.4)	0.27
E-AL, median (IQR)	1.6 (1.1–2.5)	1.0 (0.6–1.7)	0.052	1.1 (0.8–2.8)	0.32
E-PL, median (IQR)	3.0 (2.3–3.9)	2.3 (2.1–2.5)	0.06	3.5 (2.4–4.1)	0.50
E1/E2, median (IQR)	1.3 (0.9–1.9)	1.3 (1.2–1.4)	0.55	1.2 (0.8–2.0)	0.49

method. We specifically focused on healthy nulliparous women without systemic diseases. One of the strengths of the present study is the considerable homogeneity among the groups regarding parity, health conditions, indications for induction of labor, and methods of IOL used. Comparing results across studies on induction of labor and the factors that predict outcomes is challenging, primarily because there is no universally accepted definition of what constitutes a successful IOL.

Table 4. Univariate and multivariate analysis for the prediction of CS.

	Univariate analysis	Multivariate analysis
Variable	Odds ratio (95% CI)	Adjusted* odds ratio (95% CI)
Maternal height (cm)	0.90 (0.84 – 0.97)	0.91 (0.84–0.98)
BMI at delivery (kg/m²)		
≥30.0 kg/m²	1.38 (0.34 – 5.53)	1.44 (0.30–6.98)
25.0 – 29.9 kg/m²	1.17 (0.35 – 3.92)	1.39 (0.34 – 5.76)
Cervical length (cm)	1.78 (1.02 – 3.10)	1.57 (0.84 – 2.92)
E1	0.63 (0.43–0.93)	0.81 (0.46–1.41)
E3**	0.61 (0.39–0.96)	0.75 (0.44–1.27)
E5**	0.61 (0.37–1.05)	0.71 (0.38–1.33)
E-AL**	0.47 (0.25–0.88)	0.53 (0.26–1.10)
E1/E2	0.64 (0.32–1.31)	0.69 (0.31–1.52)

* adjusted for all variables shown in the table.
** variables not included in the model simultaneously due to the collinearity; E-AL and E-AL included in separate models (E-AL included in the main model).

In the last decade, cervical length has been used to predict induction outcomes; however, studies assessing its predictive value for successful induction of labor in nulliparous patients remain inconclusive.

Pre-induction cervical length with a cutoff of 28 mm may serve as a predictive marker for vaginal birth in nulliparous women induced with prostaglandins, as indicated by several studies [6, 19]. A meta-analysis by Shi et al. reviewed 12 out of 57 studies focusing on nulliparous women, none utilizing a combined method for IOL [20]. The established cutoff for a successful IOL generally ranges from 20 to 30 mm [20]. Cromi et al. found that transvaginal ultrasound could effectively

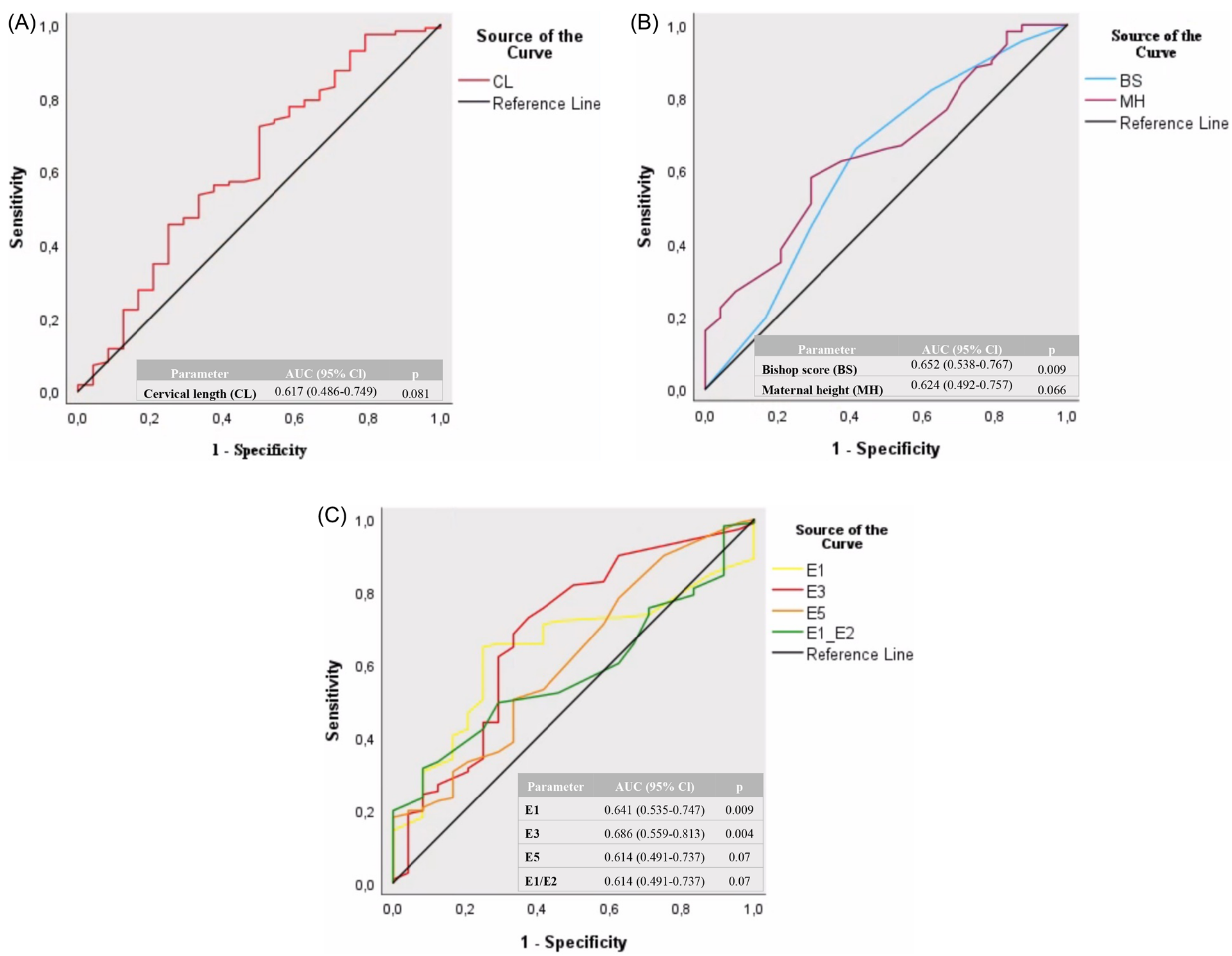

Figure 5. Prediction of vaginal delivery using CL, BS, maternal height, and cervical strain elastography. (A) : ROC curve shows the predictive ability of cervical length (red line). (B) : ROC curves compare the predictive ability of Bishop score before IOL (blue line) and maternal height (maroon line). (C) : ROC curves compare the predictive ability of cervical strain elastography – E1 - internal os (yellow line), E3 - anterior cervical lip near the cervical canal (red line), E5- the midpoint of anterior lip (orange line), E1/E2 (green line).

predict outcomes in mechanical IOL, where the CL of 25 mm or less indicated a higher likelihood of successful intervention, while the CL of 35 mm or more after Foley catheter removal was predictive of CS [21]. In our study, the mean CL was 26 mm in the vaginal delivery group, and we found no significant difference in cervical length between the vaginal delivery and CS groups. Although univariate analysis identified cervical length as a predictor for CS, multivariate analysis did not support it as an independent factor. It indicates that, in the context of using a combined method for induction, the specific type of induction method may have a more significant impact on predicting outcomes than cervical length itself. This means that the induction method's characteristics could be more important than cervical length measurements, regardless of whether the cervical length is above or below certain measurement threshold.

Previous studies have shown the posterior cervical angle (PCA) to be a predictive marker for successful labor induction, with a significant cutoff of 100 degrees in the nulliparous group, where prostaglandins or oxytocin were the induction methods [22]. Our findings align with the previously established cutoff, as we observed no significant difference in PCA between the vaginal delivery and CS groups, with values of 127.5° and 118.5°, respectively, both exceeding 100 degrees. However, despite this concordance, we did not find a relationship between PCA and mode of delivery. This lack of association may be attributed to the homogeneity of our study population, with a mean gestational age of 41 weeks (40.0 – 41.0), a point at which PCA values tend to exceed 100 degrees in most cases.

A recent meta-analysis by Shi et al. pooled data from three studies, reporting that HPD had a diagnostic odds ratio for predicting successful IOL [20]. However, two of these studies included multiparous women and identified cutoff values of HPD for vaginal birth were less than 40 mm [23] and 55 mm [24]. The present study showed no significant differences in HPD between the groups. This indicates that HPD may not be a dependable predictor of the primary outcome of IOL, but it could be used as a predictor during antenatal ultrasound examination for prediction of labor after 40 weeks of gestation. HPD is shortened at 36 to 38 weeks of gestation in singleton nulliparous women delivering before 40 weeks [25]. Hjartardóttir et al. in their study [25] proved HPD measured both at the first and last vaginal examination in active labor were associated with delivery mode and remaining time of labor among nulliparous [26]. Instead, it underscores the possible impact of fetal head position on cervical dilation and contractions, as it exerts adequate pressure on the cervix, stimulates hormone release to enhance contractions, improves the efficiency and strength of uterine contractions, and facilitates cervical softening. This factor should be considered when consulting patients before IOL, particularly for those with other risk factors for failed IOL, such as height and BMI. Khazardoost's study used other landmarks – they assessed the pre-IOL translabial distance from the fetal head to the symphysis and proved it is more sensitive than the Bishop score for predicting the mode of labor [25]. The head-symphysis distance could have been collected as well to compare which measurement is more sensitive without uterine contractions.

Phosphorylated insulin-like growth factor binding protein-1 has also been studied to predict the success of IOL. Previous studies have shown that phIGFBP-1 is better tolerated than BS [7] and has a higher sensitive value for predicting vaginal delivery after IOL in combination with increased BS and shorter CL for nulliparous women [7,27]. Our study found that a positive *Actim® Partus* test did not predict successful IOL, as there was no significant difference between vaginal delivery and CS groups. This lack of significance may stem from differing induction methods—a combined approach was used in the present study, while other relied solely on pharmacological methods. The complexity of determinants, including maternal characteristics and fetal position, likely impacts labor outcomes more than phIGFBP-1, suggesting that the choice of induction method may be the most critical factor.

Finally, we employed elastography to assess the tissue's ability to deform under pressure and return to its original shape—essentially measuring elasticity. Soft tissues exhibit excellent elasticity, deforming more readily and displaying a higher strain ratio, as the Versana Premier system software indicates. While the five-region of interest (ROI) system was previously utilized by Swiatkowska-Freund and Preis [28], we opted to include extra ROIs to additionally measure the central regions of the anterior and posterior cervical lips; we calculated two elasticity indexes (E-AL and E-PL) to evaluate the overall elasticity in the middle of each cervical lip. However, it is essential to note that each medical company that has developed strain elastography software utilizes proprietary algorithms, resulting in varied calculations and representations of tissue elasticity and stiffness. The absence of a standardized ROI positioning complicates direct comparisons of cervical elasticity measurements across studies, limiting our ability to compare specific numerical values and allowing us to analyze trends in our data relative to another research.

In the latest studies, Zhou et al. and Yang et al. performed cervical strain elastography using the semiautomatic tool ElastoScan program in their studies [29,30]. In both studies, the Hardness ratio (HR) was significantly lower in the vaginal delivery group within 24 h and was a predictive factor for successful IOL [29,30]. Our findings align with theirs, showing higher strain values in the vaginal delivery group, indicating a softer cervix. Similar conclusions have been reached in previous studies on antenatal ultrasonography among singleton nulliparous women at a gestational age 37 to 38 weeks to predict imminent delivery within 7 days – HR was significantly lower in women who delivered within 1 week of the assessment [31]. Moreover, HR holds significance in a multiparous group—it is notably higher in women who delivered after 40 weeks, but it did not substantially enhance the diagnostic accuracy of cervical length alone in predicting delivery beyond this gestational age [32]. In our study, the elasticity index of internal os had predictive value for CS in univariate analysis and was significantly higher in the vaginal delivery group. This is consistent with previous studies, who found that internal os strain was softer in women who delivered vaginally within 24 h of IOL initiation [29,30]. The study by Peralta et al. interrogating women throughout pregnancy, demonstrated that stiffness decreases as pregnancy progresses, and the external part of the cervix was significantly softer than the internal one [33]. These findings are in discordance with findings of studies of cervical elastography before IOL. It seems that the elasticity of internal os is more important than that of the external os before IOL. These parameters may indicate biochemical changes in different cervix areas and contribute to understanding the efficacy of the combined method of induction. The effective mechanism of FC seems to be due to the application of pressure on the internal os with a pressure vector in the direction of the cervix [34]. Softer cervical tissue, indicated by higher elasticity index, suggests that the cervix is more likely to dilate, facilitating vaginal delivery. Additionally, the predictive elasticity of internal os for CS highlights its importance in assessing labor outcomes. Therefore, measuring cervical elasticity could offer valuable insights into the likelihood of successful IOL.

The study evaluates various ultrasound parameters, comprehensively analyzing predictors for successful labor induction in nulliparous women at 41 weeks of gestation. By using a single induction method throughout the study population and performing multivariate analyses, the findings minimize variability and allow for more precise conclusions on the performance of the assessed parameters.

The main restriction of this study is the sample size – the number of CS for secondary outcomes were small, which could affect the results of significant differences between various parameters.

Conclusion

The predictive values of different ultrasound variables, including cervical strain elastography, for successful induction of labor were compared in this study. The strain values of the internal and anterior cervical lip near the cervical canal, and the midpoint of both the anterior and posterior lip differ between the vaginal delivery and CS groups. Nevertheless, maternal height was the sole independent predictor for CS identified in this study. This finding may be influenced by the homogeneity of the study population and the standardized induction method employed for all participants. Given our study's notably low CS rate, this supports the premise that the induction process *per se* is a significant factor in determining labor outcomes. Future prospective studies are crucial to clarify the factors affecting the success of IOL in nulliparous women. These investigations should specifically focus on the influence of induction techniques, labor management approaches, and additional clinical factors before the commencement of IOL.

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Authors contribution

Laura Rācene: Conceptualization, methodology, investigation, resources, data curation, writing – original draft, writing – review and editing, visualization. Līva Ķīse: Investigation, resources, data curation, writing – review and editing, visualization, Ieva Pitkēviča: Investigation, resources, data curation, vizualization. Zane Rostoka: Investigation, resources, data curation, visualization. Beāte Sārta: Investigation, resources, data curation. Maija Priedniece: Investigation, resources, data curation. Agnija Vecvagare: Investigation, resources, data curation. Ļubova Lapidus: Investigation, resources. Anda Ķīvīte – Urtāne: Formal analysis, writing – review and editing. Dace Rezeberga: Conceptualization, methodology, writing – review and editing, supervision. Natālija Vedmedovska: Conceptualization, methodology, writing – review and editing, supervision, funding acquisition.

Ethics statement

The study was approved by the Research Ethics Committee of Riga Stradins University (No 2-PĒK-4/152/2022), 14.03.2022.

Disclosure statement

The authors report there are no competing interests to declare. The funders had no role in the study design, collection, analyses, interpretation of data, writing of the manuscript, or the decision to publish results.

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Data availability statement

The data that support the findings of this study are available from the corresponding author, L.R., upon reasonable request.

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