Original Article

Assessment of different sonographic cervical measures to predict labor induction outcomes: a systematic review and meta-analysis

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Background: Induction of labor (IOL) is a common obstetric approach to start or encourage uterine contractions to achieve a vaginal birth. It is recommended when continuing the pregnancy may be more dangerous for the mother or baby. Different ultrasonographic measures, such as cervical length, have been investigated as possible predictors of the outcomes of IOL. This meta-analysis aimed to assess the accuracy of ultrasound measurements in anticipating successful IOL.

Methods: The study conducted a thorough search on three databases (PubMed, Scopus, and Web of Science) until 04 March 2023, to find clinical studies published in English that reported different sonographic cervical measures and their ability to predict IOL outcomes. The chosen studies were stratified based on the type of indicator reported, and a meta-analysis was conducted to determine the best indicator for both successful and failed induction. The risk of bias and concerns about the applicability of the included studies was evaluated using the Quality Assessment of Diagnostic Accuracy Studies-2 (QUADAS-2) method.

Results: This study analyzed 57 studies with 9,338 patients. Cervical length is moderately effective in predicting successful IOL, with pooled sensitivity (SN) and specificity (SP) of 0.67 and 0.70, respectively. However, cervical length had a pooled SN and SP of 0.70 and 0.61 for predicting failed IOL. The posterior cervical angle was found to have a higher pooled SN and SP of 0.79 and 0.73 for predicting successful IOL. Fetal head-perineum distance demonstrated moderate accuracy with a pooled SN, SP, positive likelihood ratio, negative likelihood ratio, diagnostic odds ratio, and area under the curve of 0.58, 0.66, 1.95, 0.36, 5.33, and 0.9992, respectively, for predicting successful IOL.

Conclusions: Fetal head-perineum distance was the most effective predictor for successful IOL compared to cervical length, which only had a moderate predictive ability. Shortening of cervical length was not a useful indicator for successful IOL. On the other hand, the posterior cervical angle was the most reliable factor for predicting failed induction. The study's findings can aid in developing more effective management strategies for IOL.

Keywords: Induction of labor (IOL); obstetrics; intervention; radiology; sonography

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Introduction

Induction of labor (IOL) is a therapeutic modality to start or encourage uterine contractions to achieve a vaginal birth (1). It is often advised when it is deemed safer to deliver the baby than to continue the pregnancy, such as in situations of pre-eclampsia, gestational diabetes, or protracted pregnancy (1,2). IOL may also be considered if the woman has a medical condition that the pregnancy might aggravate, such as heart disease or renal illness, or worries about the baby's health (2,3). Prostaglandin and oxytocin are two pharmacological agents that may be used to induce labor, as well as mechanical techniques such as stripping the membranes or inserting a Foley catheter, as well as a combination of both (4-9). Many variables, including the gestational age of the fetus, the cervical state, and the purpose for induction, influence the choice of induction technique (10,11). IOL may have many advantages, but it is not without possible dangers. The likelihood of cesarean delivery, uterine rupture, and fetal distress may increase with labor induction (9,12-14). Consequently, before deciding to continue with induction, it is crucial to weigh the risks and advantages of the operation thoroughly.

In recent years, ultrasonography assessment of the length of the cervix is a vital technique in obstetric practice for predicting the risk of preterm delivery and identifying women that do not respond to conventional therapies, like progesterone supplementation or cervical cerclage to avoid premature birth (15-18). Ultrasonic assessment of cervical length is a non-invasive and precise approach for assessing the cervix and has been found to reliably predict preterm birth in women with high-risk during mid-pregnancy (19-21).

In addition to predicting preterm delivery, ultrasonography assessment of the length of the cervix has also been investigated to potentially predict effective IOL (22-24). This is because a shorter cervix may suggest that the cervix is already in the process of ripening and preparing for labor, which increases the probability of a successful induction (25,26). Nonetheless, the information supporting the prognostic usefulness of cervical length for a successful induction is concerning (27-29), and further exploration is required to explain its relevance in this context. Besides, many ultrasonographic variables, including fetal head-perineum distance, cervical wedging, degree of cervical length shortening, and posterior cervical angle, have been investigated as predictors for successful vaginal delivery after IOL (15,30-32).

A previous meta-analysis of 31 articles found that sonographic measurements of cervical wedging and length at or near term show a modest ability to predict the success of IOL (33). However, multiple investigations have been published since the last meta-analysis. This meta-analysis aims to update the current evidence and evaluate the accuracy of ultrasound measurements of cervical wedging and length, fetal head-perineum distance, degree of cervical length shortening, and posterior cervical angle in anticipating successful IOL. By synthesizing the available evidence, we hope to provide clinicians with a better understanding of the measures that can impact effective induction and aid in developing more effective and personalized management strategies for women undergoing IOL. We present this article in accordance with the PRISMA reporting checklist (34) (available at https://qims.amegroups.com/article/view/10.21037/qims-23-507/rc).

Methods

We conducted the current meta-analysis in accordance with the PRISMA declaration standards and the review was not registered and no the protocol was not prepared. The Cochrane Handbook of Systematic Reviews and Meta-Analyses of Interventions was strictly followed at every stage (https://training.cochrane.org/). The following inclusion criteria were applied on finding the relevant articles: (I) studies on pregnant women who required IOL, (II) reporting the use of pharmacological or mechanical methods for IOL, (III) investigating either of the following outcomes: cervical length and wedging, fetal head-perineum distance, degree of cervical length shortening, and posterior cervical angle as a predictor of effective or failed IOL, and (IV) were original (i.e., recruiting human individuals only). On the other hand, our exclusion criteria were (I) articles with unreliable data for extraction and analysis, (II) non-original studies with no human data, (III) presented only as thesis or abstracts, (IV) with full texts unavailable, and (V) not published in English.

Search strategy

We ran a thorough search on three databases (PubMed, Scopus, and Web of Science) until 04 March 2023 (Table S1), by the following query: ("Labor, Obstetric" OR "Labor Pain" OR "Trial of Labor" OR "Obstetric Labor, Premature" OR "Labor, Induced" OR "Labor Stage, Third" OR "Labor Stage, Second" OR "Labor Stage, First" OR "Labor Presentation" OR "Labor Onset" OR "Obstetric Labor Complications" OR "Child Labor") AND ("induction

of labour" OR "induced labour") AND ("cervical length" OR "cervical wedging" OR "funneling cervical elastography" OR "cervical shear wave elastography" OR "uterocervical angle" OR "cervical volume" OR "Bishop score" OR "Manipal cervical scoring system"). No restrictions regarding the year or country of publication were applied. Moreover, manual searches were done to find any other possibly suitable research in the listed studies' references.

Screening

Endnote (Clarivate Analytics, PA, USA) was used to eliminate duplicate records, and the obtained references were screened in two phases: the first phase involved evaluating the titles and abstracts of all identified articles to establish their applicability to this meta-analysis, and the second step involved evaluating the full-text versions of the identified abstracts to assess their final suitability to meta-analysis. The selection process was conducted on the Rayyan website (35). All steps were conducted by at least three authors on an individual basis.

Data extraction and quality assessment

A standard data extraction sheet was used for data extraction. The extracted information included (I) study characteristics, (II) study population characteristics, (III) quality assessment domains, and (IV) outcome measures. The risk of bias and concerns about the applicability of the included studies was evaluated using the Quality Assessment of Diagnostic Accuracy Studies-2 (QUADAS-2) method (36). Independently using the tool, two reviewers used it, and a conversation settled disagreements with a third reviewer. The patient selection, index test, reference standard, and flow and time domains make up the QUADAS-2 tool. Each topic is evaluated for bias risk and questions about applicability. Bias risk is rated as being low, high, or unclear. For the patient selection and index test domains, applicability concerns are rated as low, high, or unclear; for the reference standard, flow, and time domains, they are rated as low or high.

Data synthesis and analysis

Synthesis methods

Since this meta-analysis was conducted for the study of the diagnostic test accuracy, which reported outcomes in the form of particular test(s), including sensitivity (SN), specificity (SP), positive likelihood ratio (PLR), negative likelihood ratio (NLR), and receiver operating characteristic (ROC) curves. These measures helped evaluate the performance of the diagnostic test(s) in correctly identifying true positive and true negative cases. For all outcomes, the diagnostic odds ratio (DOR) and the corresponding 95% confidence intervals (CIs) were pooled in the DerSimonian Liard meta-analysis model using Meta-disc (version 1.4 for Windows).

Choice of the meta-analysis model

The combined effect size for all outcomes was calculated using the DerSimonian Liard meta-analysis model. This approach, which uses a random effects framework, considers that the included studies represent a random sample of the population and assigns smaller studies less weight than bigger studies. This model is appropriate for contradictory or debatable estimates since it can manage a bigger standard error (SE) in the pooled estimate. As a result, the effects computed in our meta-analysis were cautious estimates that had considered any discrepancies.

Assessment of heterogeneity

In order to assess statistical heterogeneity among the studies, we used the Cochrane Q test, which involves the Chi-squared test. We then calculated the I-squared value based on the Cochrane Q test results using the equation:

$$I^2 = \left(\frac{Q - df}{Q}\right) \times 100\% \quad [1]$$

Significant heterogeneity was considered with a Chi-squared P value of <0.1 or an I-square value of 50% or more.

Certainty assessment

We performed a sensitivity analysis (leave-one-out approach) to conduct a certainty assessment to examine the evidence's validity. We conducted sensitivity analyses for each outcome in the meta-analysis, eliminating one study from each scenario to confirm that the pooled effect size was independent of a certain research.

Results

Search results

There were 2,615 results finally identified, including 309

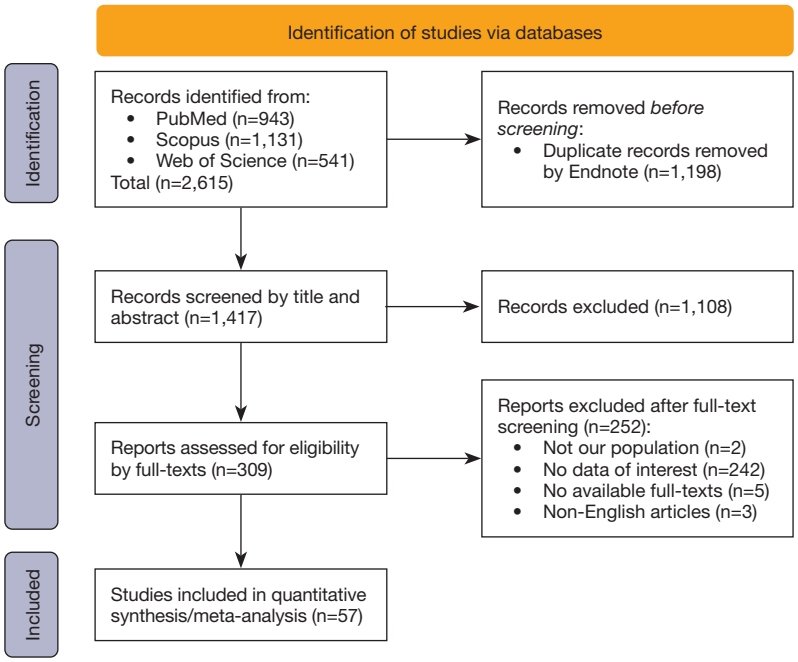

Figure 1 PRISMA flow diagram of studies' screening and selection.

articles that were qualified for full-text screening after being subjected to title and abstract screening. The meta-analysis included 57 of these articles. No further papers were included after manually searching the references of the listed studies. *Figure 1* depicts the PRISMA flow chart of this step.

Baseline characteristics

The meta-analysis included 57 trials with a total of 9,338 individuals who underwent IOL. *Table 1* exhibits the features of the included articles. Overall, according to the QUADAS-2 tool, we found that the included investigations had a moderate to low probability of bias (Figures S1,S2).

Outcomes

Cervical length for prediction of successful IOL

Pooled analysis for 36 studies with a sample size of 5,506 patients, the pooled SN, SP, PLR, NLR, DOR, and area under the curve (AUC) (SE), with 95% CI for cervical length in predicting successful IOL were 0.67 (95% CI: 0.66–0.69), 0.70 (95% CI: 0.68–0.72), 2.31 (95% CI: 1.87–2.86), 0.40 (95% CI: 0.33–0.49), 6.54 (95% CI: 4.47–9.50), and 0.78 (SE: 0.0250), respectively (*Table 2*, *Figure 2*).

The analysis of the combined results for the diagnostic odds ratio revealed that the Cochrane Q test yielded a value of 222.66 with 35 degrees of freedom, resulting in a P value <0.0001. These findings indicated compelling evidence of significant heterogeneity among the studies included in the analysis. This heterogeneity is expected due to a higher number of included studies and potential sources of heterogeneity, such as differences in study design or patient population characteristics. Therefore, a random effect model was used to customize these results, and the leave-one-out method failed to resolve this heterogeneity.

Cervical length for prediction of failed IOL

Pooled analysis for 19 studies with a sample size of 3,560 patients, the pooled SN, SP, PLR, NLR, DOR, and AUC (SE) with 95% CI for cervical length in predicting failed IOL were 0.70 (95% CI: 0.67–0.73), 0.61 (95% CI: 0.59–0.62), 1.82 (95% CI: 1.61–2.06), 0.49 (95% CI: 0.39–0.61), 4.01 (95% CI: 2.89–5.54), 0.6861 (SE: 0.0261), respectively (*Table 2*, *Figure 3*).

The analysis of the combined results for the diagnostic odds ratio revealed that the Cochrane Q test yielded a value of 52.15 with 18 degrees of freedom, resulting in a P value <0.0001. These findings indicated compelling evidence of

Table 1 A summary of the baseline characteristics

References	Design	Country/region	Sample size	Maternal age (years), mean (SD)/mean [SD]/ mean/median [range]	BMI (kg/m^2), mean (SD)/median [range]	Gestational age at induction of labor (days), mean (SD)/ mean [SD]/median [range]	Nulliparity
Abdullah 2022 (22)	A comparative clinical trial	Malaysia	294	30.30 (5.0)	26.54 (5.9)	274 (8.4)	132 (44.90%)
Al-Adwy 2018 (37)	POS	Egypt	70	26.24 (4.1)	26.94 (3.4)	NR	29 (41.40%)
Alanwar 2021 (38)	POS	Egypt	320	27.20 (3.4)	27.60 (1.4)	275.800 (5.6)	78 (33.90%)
Ali 2019 (30)	Prospective case-control	United Arab Emirates	219	26.95 (3.5)	25.78 (3.5)	217.740 (7.6)	164 (74.90%)
Alvarez-Colomo 2016 (39)	POS	Spain	151	32.60	NR	NR	103 (68.20%)
Aracic 2017 (40)	POS	Croatia	101	28.70 (5.4)	NR	278.250 (11.62)	50 (49.50%)
Athulathmudali 2021 (41)	POS	Sri Lanka	100	28.40 (4.6)	NR	279.920 (8.9)	71 (71.00%)
Bastani 2011 (42)	POS	Iran	200	29.90 (5.6)	NR	277.200 (9.8)	133 (66.67%)
Brik 2017 (43)	POS	Spain	245	32.20 (4.7)	30 (5.5)	287 [7]	165 (67.30%)
Çaliskan 2006 (44)	POS	Turkey	74	27.50 (5.7)	28 (3.5)	274.400 (8.4)	38 (51.40%)
Cheung 2010 (45)	POS	China	460	29.40 [5]	NR	NR	282 (61.30%)
Cromi 2007 (46)	POS	Italy	155	31.50 (5.1)	27.4 (5.5)	277.900 [238–294]	118 (76.10%)
Cubal 2013 (47)	POS	Portugal	197	28.61 [5]	26.49 (2.2)	285.500 (2.7)	122 (61.90%)
Daskalakis 2006 (48)	POS	Greece	137	24.30 [19–37]	28.90 [18–41.30]	280 [259–294]	137 (100%)
Gül 2020 (49)	ROS	Turkey	260	31.90 (5.49)	29.22 (3.73)	284.200 (3.6)	260 (100%)
Dögl 2011 (50)	ROS, originating from a randomized controlled trial	Norway	216	30.10 (4.7)	30.10 (4.0)	NR	NR
Eggebø 2008 (51)	ROS	Norway	275	30 [18–45]	24 [17–45]	280 [259–301]	129 (47%)
Elghorori 2006 (52)	POS	UK	104	26.70 [14–37]	NR	287 [259–294]	54 (52%)
El-Maghraby 2021 (53)	POS	Egypt	140	23.34 (4.1)	29.12 (2.57)	279 (9.9)	NR
Funghi 2018 (54)	POS	Italy	41	30.80 (4.9)	NR	NR	NR
Gabriel 2002 (55)	POS	France	179	NR	NR	NR	86 (48%)
Gillor 2017 (56)	POS	Spain	150	27.50 [24–30.70]	25 [21.50–30.10]	289.100 [275.100–291.900]	150 (100%)
Gómez Laencina 2007 (57)	POS	Spain	177	31.22 [18–46]	28.60 [20.55–47.18]	277.480 [252–294]	124 (70.10%)
Gómez-Laencina 2012 (58)	POS	Spain	177	31.22 [18–46]	28.60 [20.55–47.18]	277.480 [252–294]	124 (70.10%)
Gonen 1998 (59)	POS	Israel	86	28.40 [19–42]	NR	281.400 [238–294]	41 (48%)
Hwang 2013 (60)	POS	Korea	145	31 [22–42]	26 [19–44]	288 [259–298]	145 (100%)
Kang 2010 (61)	POS	Korea	92	31.44 (3.7)	27.90 (4.3)	266 [13]	78 (84.80%)
Kant 2016 (62)	POS	India	200	24.80	26.30 (3.1)	273 (9.8)	200 (100%)

Table 1 *(continued)*

Table 1 *(continued)*

References	Design	Country/region	Sample size	Maternal age (years), mean (SD)/mean [SD]/ mean/median [range]	BMI (kg/m^2), mean (SD)/median [range]	Gestational age at induction of labor (days), mean (SD)/ mean [SD]/median [range]	Nulliparity
Raynelda 2018 (63)	Cross-sectional observational analytical study	Indonesia	110	NR	NR	NR	98 (89.10%)
Keepanasseril 2007 (64)	POS	India	145	26.25 (4.39)	30.23 (2.4)	37.75 (2.0)	145 (100%)
Khandelwal 2018 (65)	POS	India	66	NR	NR	NR	62 (93.90%)
Khazardoost 2016 (66)	Cross-sectional study	Iran	100	25.10 (4.4)	24.12 (3.4)	NR	NR
Kwon 2021 (29)	POS	Korea	165	32.50 (2.6)	21.90 (3.3)	39 (0.78)	NR
Li 2023 (25)	ROS	Taiwan	138	30.19 (5.5)	29.83 (0.6)	77.80 (0.07)	79 (57.24%)
Meijer-Hoogeveen 2009 (67)	POS	The Netherlands	225	31 (5.77)	25.24 (2.79)	NR	150 (67%)
El Mekkawi 2019 (68)	POS	Egypt	210	24.13 (2.34)	NR	38 (1.2)	210 (100%)
Pandis 2001 (24)	POS	UK	240	29.70 (8.1)	30.85 (9.7)	40.25 (1.5)	128 (53.30%)
Park 2007 (69)	POS	Korea	161	30.25 (2.9)	NR	21.30 (0.05)	161 (100%)
Park 2012 (70)	POS	Korea	146	31.25 (2.3)	NR	34.20 (0.1)	111 (76%)
Paterson-Brown 1991 (71)	POS	UK	50	NR	NR	NR	NR
Pitarello 2013 (72)	POS	Brazil	190	24.55 (4.9)	28.45 (0.6)	40.05 (0.6)	NR
Rane 2003 (73)	POS	UK	382	NR	NR	41.25 (0.3)	192 (50.20%)
Rathore 2021 (74)	Cross-sectional study	India	84	23.22 (3.2)	25.97 (3.5)	NR	NR
Reis 2003 (75)	POS	Italy	111	32 (1.7)	NR	40.38 (0.01)	NR
Roman 2004 (76)	POS	France	106	31.20 (5.3)	NR	39.70 (0.1)	NR
Rozenberg 2005 (77)	POS	France	266	29.55 (1.75)	NR	39.60 (0.9)	189 (71%)
Tan 2007 (78)	POS	Malaysia	249	30.45 (0.2)	NR	39.85 (0.1)	109 (43.70%)
Tan 2006 (79)	POS	Malaysia	152	30.55 (0.3)	NR	NR	65 (42.80%)
Tanir 2008 (80)	POS	Turkey	43	26.10 (0.7)	24.65 (0.6)	38.40 (0.2)	43 (100%)
Türkyilmaz 2020 (81)	POS	Turkey	78	25.70 (5.5)	23.80 (3.7)	25.20 (6.4)	78 (100%)
Uyar 2009 (82)	POS	Turkey	189	24 (4.1)	25.60 (2.9)	40 (1.4)	55 (29%)
Uzun 2013 (83)	Randomized trial	Turkey	90	24.68 (0.3)	27.88 (0.2)	288.065 (0.4)	90 (100%)
Vallikkannu 2017 (84)	POS	Malaysia	193	28.60 (1.6)	29.68 (2.1)	39.45 (0.7)	193 (100%)
Ware 2000 (85)	POS	Atlanta	77	NR	NR	40 (1.7)	32 (42%)
Yang 2004 (86)	POS	Korea	105	27.30 (3.2)	NR	40 (1.7)	78 (74%)
Yang 2021 (87)	ROS	Korea	205	32 (5.3)	24.80 (4.96)	NR	125 (61%)
Zhou 2021 (88)	POS	China	97	29 (1.6)	20.97 (1.03)	38.88 (0.2)	NR

SD, standard deviation; BMI, body mass index; POS, prospective observational study; NR, not reported; ROS, retrospective observational study.

Table 2 Summary of the accuracy results of all indicators for the prediction of IOL

Indicator	Pooled studies (N)	Patients (N)	Pooled SN (95% CI)	Pooled SP (95% CI)	Pooled PLR (95% CI)	Pooled NLR (95% CI)	Pooled DOR (95% CI)	AUC (SE)
CL for successful IOL	36	5,506	0.67 (0.66–0.69)	0.70 (0.68–0.72)	2.31 (1.87–2.86)	0.40 (0.33–0.49)	6.54 (4.47–9.50)	0.78 (0.0250)
CL for failed IOL	19	3,560	0.70 (0.67–0.73)	0.61 (0.59–0.62)	1.82 (1.61–2.06)	0.49 (0.39–0.61)	4.01 (2.89–5.54)	0.6861 (0.0261)
CW for failed IOL	8	2,851	0.35 (0.31–0.38)	0.8 (0.74–0.85)	1.71 (1.22–2.40)	0.78 (0.67–0.91)	2.29 (1.43–3.68)	0.6555 (0.0742)
CLS for successful IOL	2	257	0.77 (0.70–0.83)	0.61 (0.50–0.72)	2.01 (1.48–2.74)	0.36 (0.25–0.52)	5.72 (2.84–11.52)	0.5 (0.0)
PCA for successful IOL	7	1,345	0.79 (0.76–0.82)	0.73 (0.67–0.77)	2.48 (1.89–3.25)	0.30 (0.21–0.43)	9.77 (5.15–18.54)	0.8484 (0.0425)
PCA for failed IOL	3	550	0.67 (0.59–0.74)	0.61 (0.56–0.66)	2.36 (0.70–7.97)	0.45 (0.10–1.97)	5.37 (0.40–72.47)	0.8564 (0.0265)
FHPD for successful IOL	3	594	0.58 (0.53–0.63)	0.66 (0.58–0.73)	1.95 (0.12–31.66)	0.36 (0.02–6.70)	5.33 (0.04–763.32)	0.9992 (0.0094)

IOL, induction of labor; SN, sensitivity; CI, confidence interval; SP, specificity; PLR, positive likelihood ratio; NLR, negative likelihood ratio; DOR, diagnostic odds ratio; AUC, area under the curve; SE, standard error; CL, cervical length; CW, cervical wedging; CLS, cervical length shortening; PCA, posterior cervical angle; FHPD, fetal head-perineal distance.

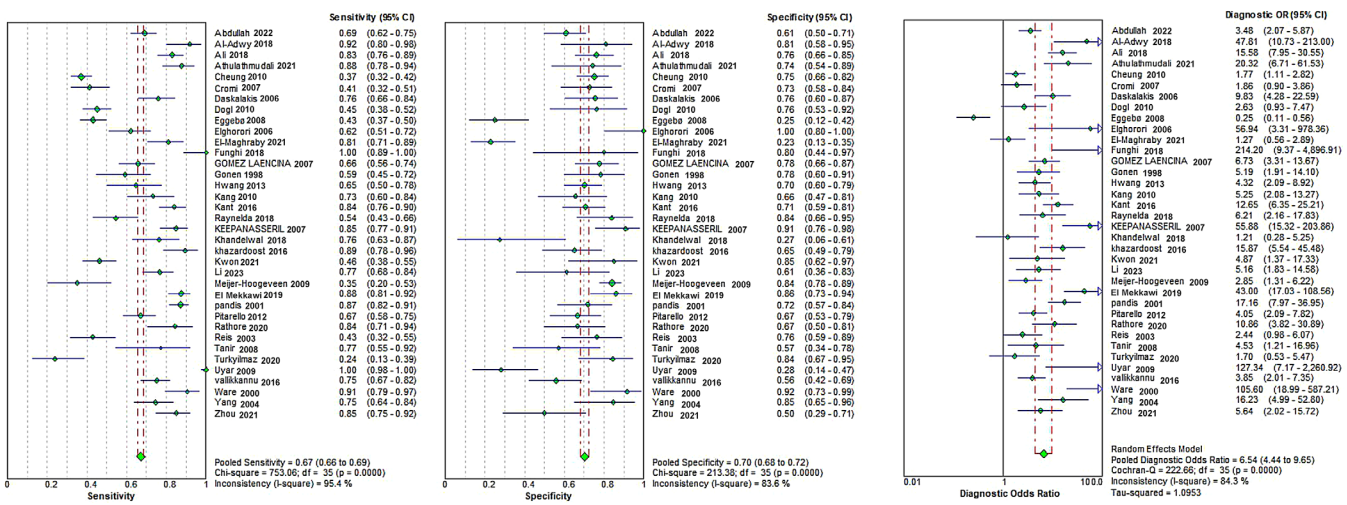

Figure 2 Forest plot of sensitivity, specificity, and diagnostic OR for CL in predicting successful induction of labor. CI, confidence interval; OR, odds ratio; CL, cervical length.

significant heterogeneity among the studies included in the analysis.

Posterior cervical angle for prediction of successful IOL

Pooled analysis for seven studies with a sample size of 1,345 patients, the pooled SN, SP, PLR, NLR, DOR, and AUC (SE), with 95% CI for posterior cervical angle in predicting successful IOL were 0.79 (95% CI: 0.76–0.82), 0.73 (95% CI: 0.67–0.77), 2.48 (95% CI: 1.89–3.25), 0.30 (95% CI: 0.21–0.43), 9.77 (95% CI: 5.15–18.54), 0.8484 (SE: 0.0425), respectively (*Table 2*, *Figure 4A*).

The analysis of the combined results for the diagnostic

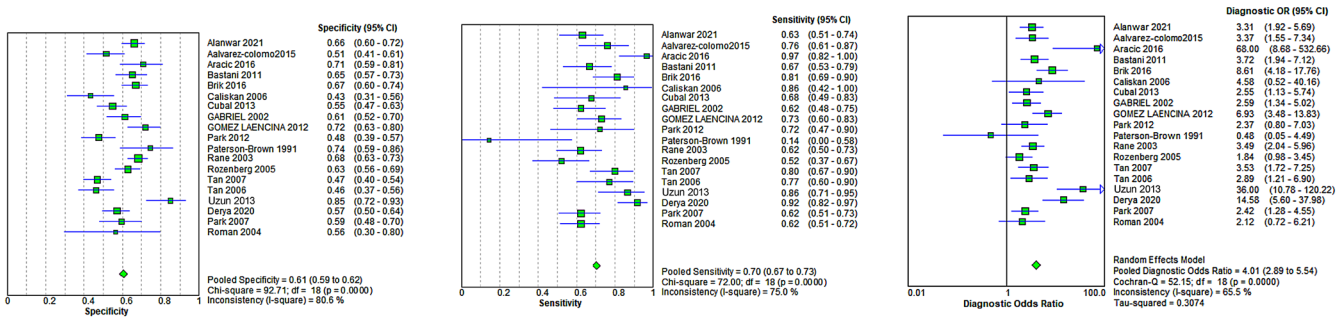

Figure 3 Forest plot of sensitivity, specificity, and diagnostic OR for CL in predicting failed induction of labor. CI, confidence interval; OR, odds ratio; CL, cervical length.

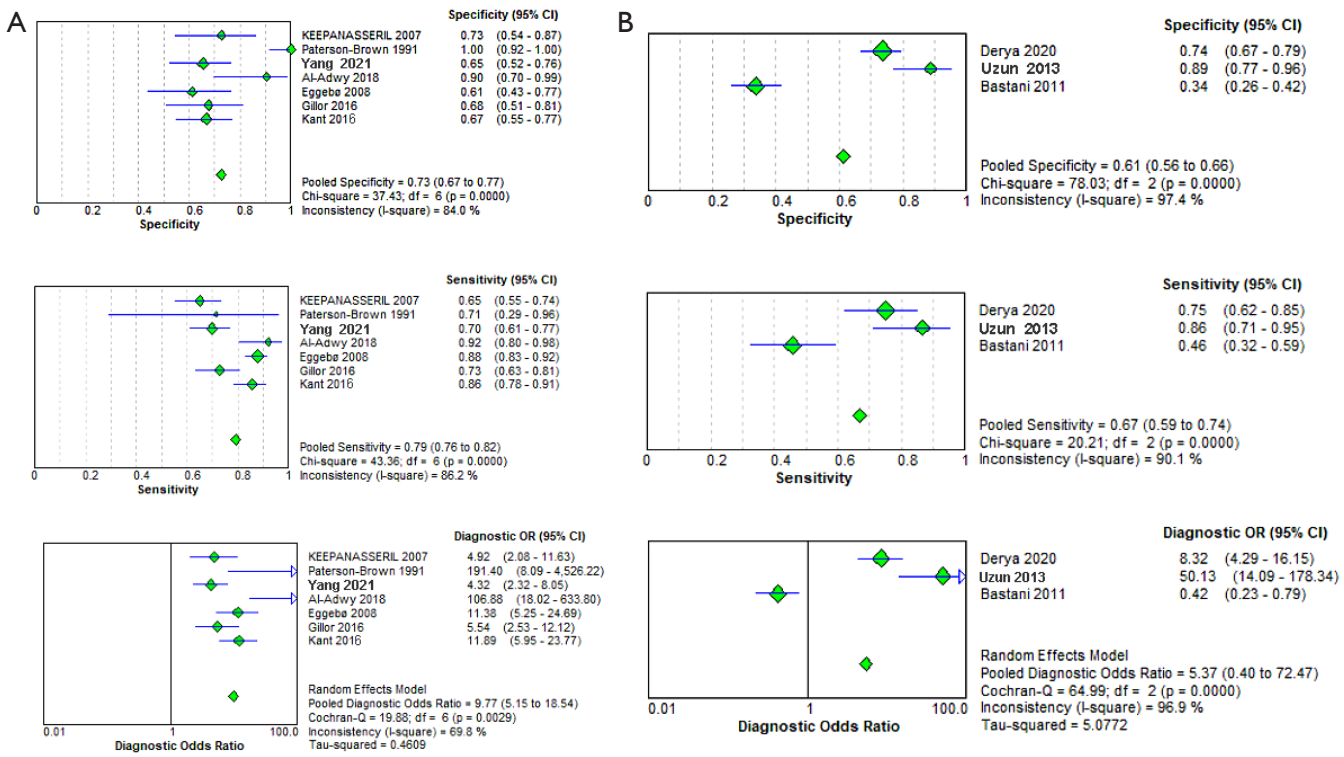

Figure 4 Forest plot of sensitivity, specificity, and diagnostic OR for posterior cervical angle in predicting (A) successful and (B) failed induction of labor. CI, confidence interval; OR, odds ratio.

odds ratio revealed that the Cochrane Q test yielded a value of 19.88 with 6 degrees of freedom, resulting in a P value <0.0001. These findings indicated compelling evidence of significant heterogeneity among the studies included in the analysis.

Posterior cervical angle for prediction of failed IOL

Pooled analysis for three studies with a sample size of 550 patients, the pooled SN, SP, PLR, NLR, DOR, and AUC (SE), with 95% CI for posterior cervical angle in predicting failed IOL were 0.67 (95% CI: 0.59–0.74), 0.61 (95%

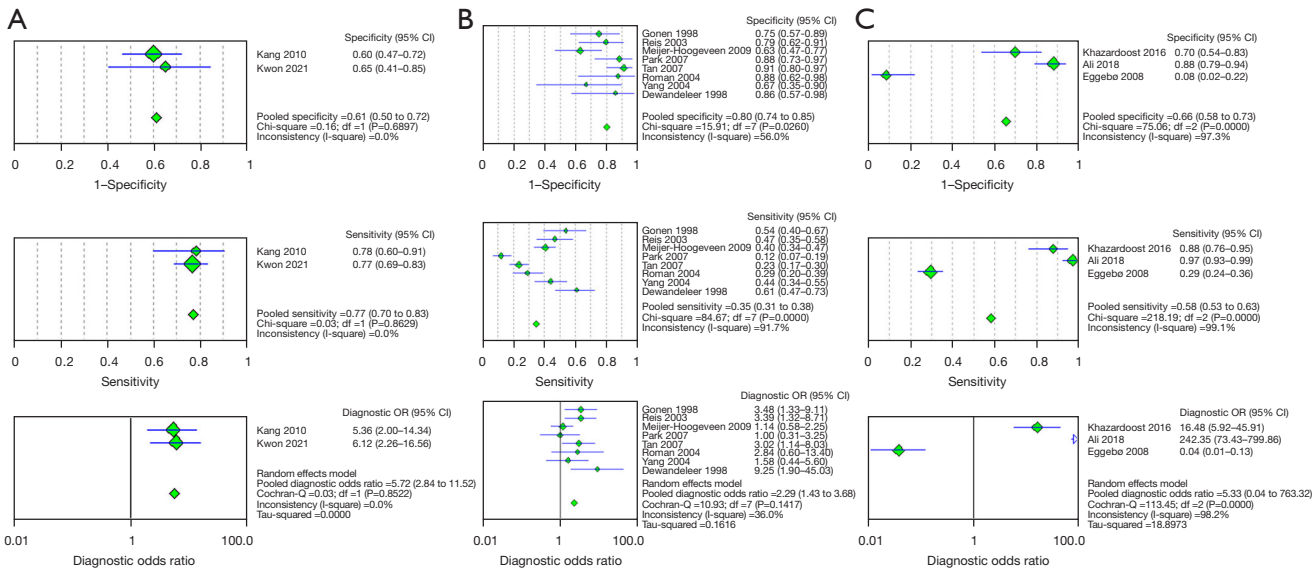

Figure 5 Forest plot of sensitivity, specificity, and diagnostic OR of (A) CL shortening, (B) cervical wedging, and (C) feto-perineal head distance in predicting successful induction of labor. CI, confidence interval; OR, odds ratio; CL, cervical length.

CI: 0.56–0.66), 2.36 (95% CI: 0.70–7.97), 0.45 (95% CI: 0.10–1.97), 5.37 (95% CI: 0.40–72.47), 0.8564 (SE: 0.0265), respectively (*Table 2*, *Figure 4B*).

The analysis of the combined results for the diagnostic odds ratio revealed that the Cochrane Q test yielded a value of 64.99 with 2 degrees of freedom, resulting in a P value <0.0001. These findings indicated compelling evidence of significant heterogeneity among the studies included in the analysis.

Cervical length shortening for prediction of successful IOL

Pooled analysis for two studies with a sample size of 257 patients, the pooled SN, SP, PLR, NLR, DOR, and AUC (SE) with 95% CI for cervical length shortening in predicting successful IOL were 0.77 (95% CI: 0.70–0.83), 0.61 (95% CI: 0.50–0.72), 2.01 (95% CI: 1.48–2.74), 0.36 (95% CI: 0.25–0.52), 5.72 (95% CI: 2.84–11.52), 0.5 (SE: 0.0), respectively (*Table 2*, *Figure 5A*).

The analysis of the combined results for the diagnostic odds ratio revealed that the Cochrane Q test yielded a value of 0.03 with 1 degree of freedom, resulting in a P value of 0.8522. These findings indicated compelling no heterogeneity among included studies.

Cervical wedging for prediction of failed IOL

Pooled analysis for eight studies with a sample size of 2,851 patients (59,67,69,75,76,78,86,89), the pooled SN, SP, PLR, NLR, DOR, and AUC (SE), with 95% CI for cervical wedging in predicting failed IOL were 0.35 (95% CI: 0.31–0.38), 0.8 (95% CI: 0.74–0.85), 1.71 (95% CI: 1.22–2.40), 0.78 (95% CI: 0.67–0.91), 2.29 (95% CI: 1.43–3.68), 0.6555 (SE: 0.0742), respectively (*Table 2*, *Figure 5B*).

The analysis of the combined results for the diagnostic odds ratio revealed that the Cochrane Q test yielded a value of 10.93 with 7 degrees of freedom, resulting in a P value of 0.1417. These findings indicated no significant heterogeneity among the studies included in the analysis.

Fetal head-perineum distance for prediction of successful IOL

Pooled analysis for three studies with a sample size of 594 patients, the pooled SN, SP, PLR, NLR, DOR, and AUC (SE), with 95% CI for fetal head-perineum distance in predicting successful IOL were 0.58 (95% CI: 0.53–0.63), 0.66 (95% CI: 0.58–0.73), 1.95 (95% CI: 0.12–31.66), 0.36 (95% CI: 0.02–6.70), 5.33 (95% CI: 0.04–763.32), 0.9992 (SE: 0.0094), respectively (*Table 2*, *Figure 5C*).

The analysis of the combined results for the diagnostic odds ratio revealed that the Cochrane Q test yielded a value of 113.45 with 2 degrees of freedom, resulting in a P value <0.0001. These findings indicated compelling evidence of significant heterogeneity among the studies included in the analysis.

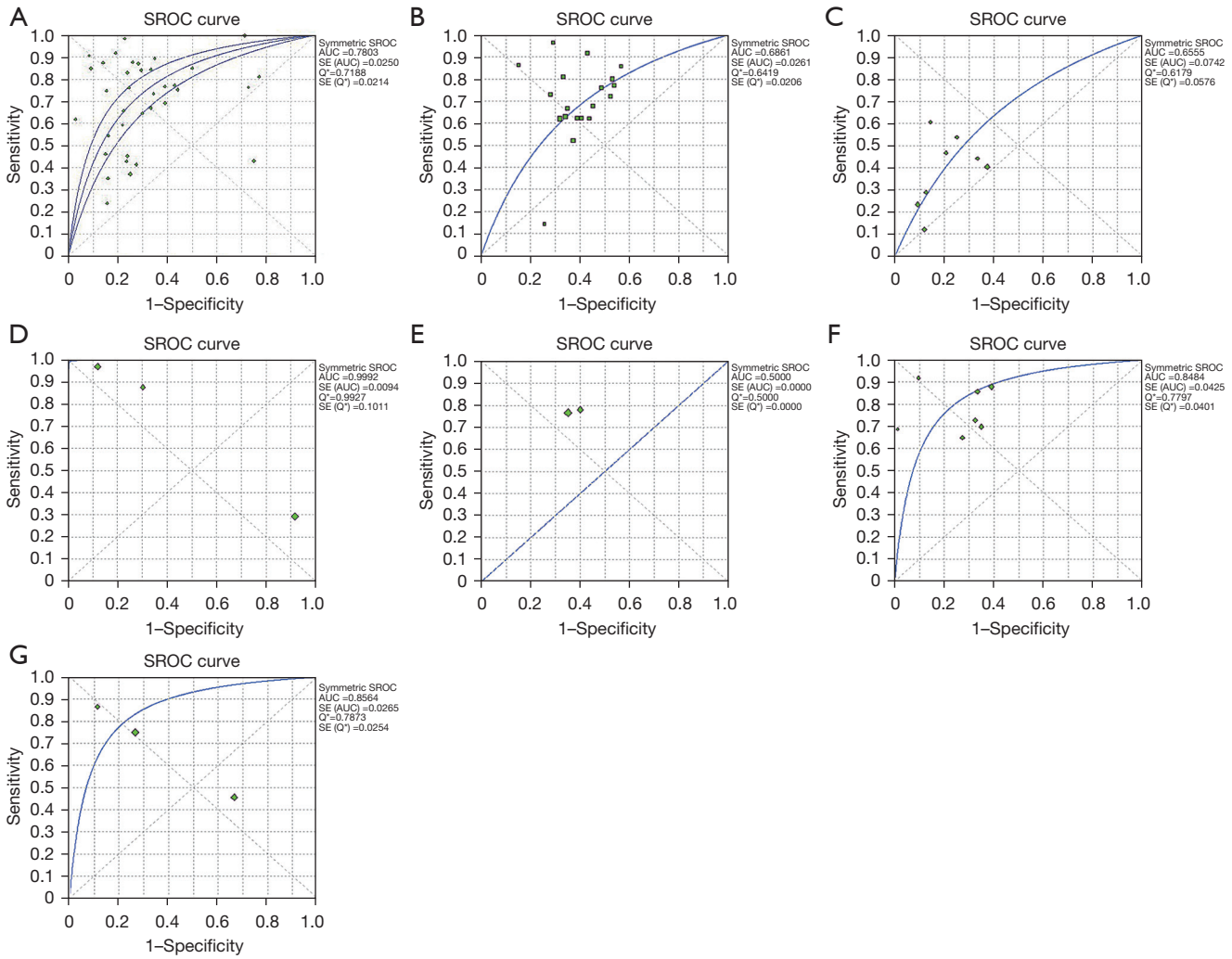

Figure 6 SROC curve of CL for predicting (A) successful and (B) failed IOL, (C) cervical wedging, (D) fetal-perineal distance, (E) cervical shortening and (F) posterior cervical angle of successful IOL, and (G) posterior cervical angle of failed IOL. SROC, summary receiver operating characteristic; AUC, area under the curve; SE, standard error; CL, cervical length; IOL, induction of labor.

Moreover, we presented the AUC (SE) for all of the reported variables in *Figure 6A-6G*. The outcomes reported by each study included in the meta-analysis are presented in Table S2. The cutoff values for each outcome reported by the individual studies are presented in Table S3.

Discussion

IOL is a general obstetric procedure that utilizes artificial techniques to initiate the onset of labor (1). The bishop score has been the go-to method for assessing the cervix's condition and predicting successful IOL for a long time. However, it has some limitations, such as inconsistencies among observers. Thus, recent attempts have explored other options for anticipating a successful IOL. Ultrasound scanning has become a more feasible option, with reduced variability, lower cost, and less invasiveness, and has shown promise as an alternative to the bishop score (78). Despite multiple studies testing the effectiveness of ultrasound measurements of the cervix in predicting successful induction, their outcomes have been inconsistent.

This systematic review and meta-analysis included 57 studies with 9,338 patients to evaluate the effectiveness of various ultrasonographic measures in predicting successful IOL. The results showed that fetal head-perineum distance had the highest diagnostic odds ratio for predicting

successful IOL, followed by the posterior cervical angle, cervical length, and cervical length shortening. The feto-pelvic distance also had the highest AUC for predicting successful IOL, followed by the posterior cervical angle and length. However, cervical length shortening showed no discriminative ability to predict successful IOL, as its AUC was only 0.5. Based on the reported SN and SP, the best predictor for successful IOL was the posterior cervical angle, followed by cervical length shortening and cervical length. The study suggested that fetal-perineal distance may be the most useful predictor for successful IOL compared to cervical length, which has a moderate predicting ability for successful IOL. Cervical length alone has a moderate ability to predict successful IOL; therefore, its combination with other indicators is important. Therefore, the combination of fetal head-perineum distance and cervical length can be useful predictors for successful IOL. This study illustrated three indicators for predicting failed induction: cervical length, cervical wedging, and posterior cervical angle. The posterior cervical angle showed the best indicator based on the AUC, DOR, SN, and SP. This was followed by the cervical length, which had a double odd ratio compared to cervical wedging and higher AUC.

In studies related to IOL, certain indicators are more commonly reported than others. One such commonly used method is the measurement of cervical length, as it is easy to perform and interpret and it provides a clear image of the cervix in almost all cases. However, it is important to note that many studies do not mention the possibility of uninterpretable results or withdrawals when using this method. Our meta-analysis included many studies that reported on cervical length, and our findings are consistent with the results of a previously published meta-analysis by Hatfield *et al.* (90). However, our overall results suggested that larger sample sizes increase the statistical power to predict the moderate ability of cervical length for predicting IOL outcomes.

Our meta-analysis provides greater statistical power to identify the best predictor of IOL outcome. Additionally, our study is unique in that it investigates the predictive ability of cervical length shortening and fetal head-premium distance for IOL outcomes, which had not been previously explored in meta-analyses. Hatfield *et al.* (90) and Verhoeven *et al.* (33) included evidence up to 2007 and 2013, respectively, but our study included all published evidence up to the present, as well as 29 additional studies which had never been included in previous meta-analyses. Our findings indicated that cervical length alone is a moderate predictor of IOL outcome but its predictive ability is still relatively weak, requiring further combination with other indicators, consistent with Verhoeven *et al.*'s results (33) and different from the findings of Hatfield *et al.* (90). This difference may be attributed to the higher sample size in Verhoeven *et al.* (33) and our study. A previous systematic review reported that the bishop score had moderate SN and low SP for predicting C-sections, with values of 0.78 and 0.44, respectively, which are similar to the predictive ability of cervical length for failed IOL in our study, with values of 0.70 and 0.61, respectively (91).

Strengths and limitations

The main strength of this systematic review is the large number of the included studies and the huge sample size of included patients. Moreover, most of the reported outcomes did not have a significant heterogeneity, which is a remarkable indicator of the validity of these outcomes. One significant limitation of this paper is its heterogeneity, which could be attributed to various factors. Firstly, the included studies reported data differently, such as parity, with some studies including only nulliparous participants while others including both nulliparous and multiparous participants. Additionally, there was variation in the definition of successful and failed induction endpoints, with some studies using cesarean delivery for fetal distress and others using the active phase of labor endpoint, which has been a topic of debate. Therefore, the heterogeneity of some outcomes may interfere with the interpretation of results. Accordingly, we encourage future researchers to conduct further studies and put inconsideration points to make this heterogeneity high. Secondly, there was heterogeneity in the methods of IOL and indications for cesarean delivery, which could have affected the accuracy of the results. A limitation of the meta-analysis was that it only considered single variable without exploring whether multiple sonographic measures had any additional value to the bishop score. To address this limitation, a multivariable approach combining various factors such as the method of induction, gestational age, and parity would be necessary to improve the accuracy of prediction models. Thus, further research using this approach is recommended.

Conclusions

This study showed that fetal head-perineum distance might be the most useful predictor for successful IOL compared

to the cervical length, which has a moderate predicting ability for successful IOL, and cervical length shortening has no discriminative ability to predict successful IOL. The posterior cervical angle showed the best indicator for predicting failed induction, based on AUC, DOR, SN, and SP, followed by cervical length. However, there are certain limitations to the study. The heterogeneity in the reported data among included studies, variation in methods of IOL, and the indication for cesarean delivery may limit the findings' generalizability. Moreover, the study used a single-variable approach; thus, a multivariable approach is necessary to determine the added value of measuring multiple sonographic measures to the bishop score. In addition, further studies with larger sample sizes and multivariable approaches are necessary to confirm these findings and determine the added value of measuring multiple sonographic measures to the bishop score.

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Footnote

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