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OBSTETRICS

Labor progress determined by ultrasound is different in women requiring cesarean delivery from those who experience a vaginal delivery following induction of labor

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BACKGROUND: The diagnosis of labor dystocia generally is determined by the deviation of labor progress, which is assessed by the use of a partogram. Recently, intrapartum transperineal ultrasound for the assessment of fetal head descent has been introduced to assess labor progress in the first stage of labor in a more objective and noninvasive way.

OBJECTIVE: The objective of the study was to determine the differences in labor progress by the use of serial transperineal ultrasound assessment of fetal head descent between women having vaginal and cesarean delivery.

STUDY DESIGN: This was a prospective longitudinal study performed in 315 women with singleton pregnancy who were undergoing labor induction at term between December 2016 and December 2017. Paired assessment of cervical dilation and fetal head station by vaginal examination and transperineal ultrasonographic assessment of parasagittal angle of progression and head-perineum distance were made serially after the commencement of labor induction. According to the hospital protocol, assessment was performed every 24 hours and 4 hours, respectively, during latent and active phases of labor. The researchers and the clinical team were blinded to each other's findings. The repeated measures data were analyzed by mixed effect models. To determine the effect of mode of delivery on the association between parasagittal angle of progression and head-perineum distance against fetal head station and cervical dilation, the significance of the interaction term between each mode of delivery and fetal head station or cervical dilation was determined, which accounted for parity and obesity. Area under receiver-operating characteristic curve was used to evaluate the performance of serial intrapartum sonography in predicting women with cesarean delivery because of failure to progress.

RESULTS: The total number of paired vaginal examination and ultrasound assessments was 1198, with a median of 3 per woman. The median assessment-to-assessment interval was 4.6 hours (interquartile range, 4.3—5.1 hours). Women who achieved vaginal delivery (n=261) had steeper slopes of parasagittal angle of progression and head-perineum distance against fetal head station and cervical dilation than those who achieved cesarean delivery (n=54). Objectively, an additional decrease of 5.11 and 1.37 degrees in parasagittal angle of progression was observed for an unit increase in fetal head station and cervical dilation, respectively, in women who required cesarean delivery ($P<.01$; $P=.01$), compared with women who achieved vaginal delivery, after taking account of repeated measures from individuals and confounding factors. The respective additional increases in head-perineum distance for a unit increase in fetal head station and cervical dilation were 0.27 cm ($P<.01$) and 0.12 cm ($P<.01$). A combination of maternal characteristics with the temporal changes of parasagittal angle of progression for an unit increase in fetal head station achieved an area under receiver-operating characteristic curve of 0.85 (95% confidence interval, 0.76—0.94), with sensitivity of 79% and specificity of 80%, for the prediction of women who required cesarean delivery because of failure to progress.

CONCLUSION: The differences in labor progress between vaginal and cesarean delivery have been illustrated objectively by serial intrapartum transperineal ultrasonographic assessment of fetal head descent. This tool is potentially predictive of women who will require cesarean delivery because of failure to progress.

Key words: angle of progression, area under the receiver-operating characteristic curve, cesarean delivery, delivery, dystocia, epidural, failure to progress, fetal head station, head-perineum distance, induction of labor, labor progress, obesity, partogram, sonopartogram, transperineal ultrasound, vaginal delivery

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Labor dystocia is defined by the slow and abnormal progress of labor.[1−7] Failure to progress in labor is the leading indication for primary cesarean delivery and resulted in 19,000 maternal deaths in 2013.[3,8−10] Labor dystocia usually is diagnosed by deviation from the expected progress of labor, which is assessed by the use of "partogram" where clinical findings by serial digital vaginal examination (which includes cervical dilation, fetal head station and position, presence of caput succedaneum, and moulding) are recorded over time.[1,11−16]

The major limitations of digital vaginal examination, although considered the gold standard method in assessment of labor progress, are that it is subjective,[17,18] causes discomfort, and may introduce infection.[19−23] Intrapartum transperineal ultrasound for the assessment of fetal head descent by angle of progression (AOP)[24] and head-perineum distance (HPD)[25] has been introduced to assess labor progress in a more objective and noninvasive way.[26−46] Several studies have shown that intrapartum transperineal ultrasound examination is more accurate than clinical examination in the assessment of the fetal head station and the

AJOG at a Glance

Why was this study conducted?
The purpose of this study was to evaluate the differences in ultrasound-determined labor progress between women who have vaginal and cesarean delivery.

Key findings
Cesarean delivery was associated with a slower rate of fetal head descent, which is determined by serial intrapartum ultrasound assessment of parasagittal angle of progression and head-perineum distance, than vaginal delivery. A combination of maternal characteristics with the temporal changes of parasagittal angle of progression achieved an area under receiver-operating characteristic curve of 0.85, with sensitivity and specificity of 80%, for the prediction of women who will require cesarean delivery because of failure to progress in labor.

What does this add to what is known?
Serial intrapartum transperineal ultrasound assessment of fetal head descent can differentiate women who can have a vaginal delivery or who require a cesarean delivery. This tool is potentially predictive of women who require cesarean delivery because of failure to progress in labor.

prediction of arrest of labor.[27,30] However, most of the studies to date have evaluated only the use of the transperineal ultrasound parameters as a single assessment in the prediction of mode of delivery in either the first or second stage of labor.[26,28,31,39,44,47—51]

To improve the objectivity in the assessment of labor progress and diagnosis of labor dystocia, it has been proposed that serial assessment with intrapartum transperineal ultrasound can be integrated with current obstetric practice.[52] Hassan et al[52] performed a prospective study in 20 women in the first stage of labor, which included 52 paired digital vaginal examination and ultrasound assessments and demonstrated the feasibility of the use of ultrasound in the first stage of labor and

TABLE 1
Characteristics of the study population

Variable	Vaginal delivery (n=261)	Cesarean delivery (n=54)	P value[a]
Maternal age, y[b]	32.2 (29.0—35.5)	33.9 (30.1—36.8)	.013
≥35, n (%)	76 (29.1)	24 (44.4)	.028
<35, n (%)	185 (70.9)	30 (55.6)	
Maternal weight, kg[b]	67.3 (61.4—75.2)	69.6 (63.1—77.1)	.187
Maternal height, cm[b]	158 (155—162)	155.5 (153—159)	.001
Maternal body mass index, kg/m²[b]	26.9 (24.8—29.6)	28.9 (26.7—31.2)	.002
≥30, n (%)	58 (22.2)	18 (33.3)	.082
<30, n (%)	203 (77.8)	36 (66.7)	
Racial origin, n (%)			.314
Chinese	260 (99.6)	53 (98.1)	
Non-Chinese	1 (0.4)	1 (1.9)	
Parity, n (%)			<.001
Nulliparous	145 (55.6)	46 (85.2)	
Parous	116 (44.4)	8 (14.8)	
Indications for induction of labor, n (%)			.080
Postterm	126 (48.3)	19 (35.2)	
Diabetes mellitus	47 (18.0)	11 (20.4)	
Hypertension	12 (4.6)	6 (11.1)	
Fetal growth restriction	11 (4.2)	1 (1.9)	
Oligohydramnios	11 (4.2)	4 (7.4)	
Macrosomia	21 (8.0)	9 (16.7)	
Others	33 (12.6)	4 (7.4)	

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TABLE 1
Characteristics of the study population (continued)

Variable	Vaginal delivery (n=261)	Cesarean delivery (n=54)	P value[a]
Estimated fetal weight, g[b]	3,276 (3,001.5—3,571.6)	3,455 (3,100—3,711)	.119
Bishop score[b]	6 (4—6)	3 (2—4)	<.001
Method of induction of labor, n (%)			
Propess[c]	111 (42.5)	42 (77.8)	<.001
Mechanical methods	150 (57.5)	12 (22.2)	
Oxytocin administration, n (%)			.526
Yes	177 (67.8)	39 (72.2)	
No	84 (32.2)	15 (27.8)	
Gestation age at delivery, wk[b]	40 (38.1—41.0)	38.7 (38.0—41.0)	.067
Birthweight, g[b]	3,263 (3,027.5—3,552.5)	3,420 (3,030.0—3,651.2)	.204
Epidural anesthesia, n (%)			.016
Yes, n (%)	9 (3.4)	6 (11.1)	
No, n (%)	252 (96.6)	48 (88.9)	
Labor duration, hr[b]	5.7 (2.9—10.2)	13.4 (9.1—20.3)	<.001
Induction-to-delivery interval, hr[b]	11.3 (6.1—26.9)	37.9 (21.1— 50.7)	<.001
Apgar score at 1 min[b]	9 (9—9)	9 (8—9)	.354
Apgar score at 5 min[b]	10 (10—10)	10 (9—10)	.138
Arterial blood gas pH[b]	7.26 (7.10—7.30)	7.29 (7.25—7.32)	.004

[a] Statistically significant at $P<.05$; [b] Data are given as median (interquartile range); [c] Ferring Pharmaceuticals, Saint-Prex, Switzerland.

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the development of a "sonopartogram." The authors concluded that data acquisition for labor progress was more successful with the use of the sonopartogram than the conventional partogram.

Our group recently reported on a prospective longitudinal study in 261 women with singleton pregnancy who underwent labor induction at term and who achieved vaginal delivery. Serial paired assessments of cervical dilation and fetal head station by vaginal examination with transperineal ultrasonographic assessment of fetal head descent were performed after the commencement of labor induction until full cervical dilation.[53] The study demonstrated that parity, obesity, methods of labor induction, and the use of epidural anesthesia affected ultrasound-determined labor progress in the first stage of labor.[53] Thus far, no study has determined the differences in labor progress in women who have a vaginal delivery or require a cesarean delivery by the use of serial intrapartum transperineal ultrasound assessment. The objective of the study was to determine the differences in labor progress, which was determined by serial transperineal ultrasound assessment of fetal head descent, between women who had vaginal and cesarean delivery, accounting for known factors that affect ultrasound-determined labor progress including obesity, parity, methods of labor induction, and epidural anesthesia.

Materials and Methods
This was a prospective longitudinal study performed in women with singleton pregnancy who underwent induction of labor at term in a single maternity unit in Hong Kong SAR between December 2016 and December 2017. Inclusion criteria for the study were pregnant women with a live fetus in cephalic presentation and intact membranes who underwent induction of labor between 37^{+0} and 42^{+6} weeks gestation for various indications. Written informed consent was obtained from the women who agreed to participate in the study, which was approved by the Institutional Review Board (Joint Chinese University of Hong Kong—New Territories East Cluster Clinical Research Ethics Committee, Reference Number CRE-2016.338).

Ultrasound assessment
Transperineal ultrasound assessment was carried out by 6 operators (P.C., A.H.W.K., W.T.T., W.T.L., W.W.Y.C., J.H.), who have had at least 3 year's obstetric ultrasound experience. Examinations were performed with the woman in a supine position and with an empty bladder. Two-dimensional transperineal scan was performed to assess the parasagittal AOP (psAOP) and HPD by the Voluson P8 ultrasound machine (GE Healthcare, Tiefenbach, Austria) as previously described.[44,53]

The effect of mode of delivery on the association between parasagittal angle of progression and head-perineum distance against cervical dilation or fetal head station without being controlled for confounders

Variable	Parasagittal angle of progression		Head-perineum distance	
	Estimate (standard error)	P value[a]	Estimate (standard error)	P value[a]
Fetal head station				
Fetal head station	11.4 (0.35)	<.01	−0.50 (0.02)	<.01
Cesarean delivery	−15.3 (2.71)	<.01	0.75 (0.16)	<.01
Fetal head station and cesarean delivery	−5.28 (1.15)	<.01	0.27 (0.07)	<.01
Cervical dilation				
Cervical dilation	7.12 (0.49)	<.01	−0.30 (0.01)	<.01
Cesarean delivery	−2.04 (1.93)	.29	−0.001 (0.13)	.99
Cervical dilation and cesarean delivery	−1.35 (0.51)	.01	0.12 (0.03)	<.01

[a] Statistically significant at $P<.05$.

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Paired assessment of fetal head station and cervical dilation by vaginal examination and transperineal ultrasonographic assessment of fetal head descent (psAOP and HPD) were made serially after the commencement of induction of labor until full cervical dilation. Specifically, according to the hospital protocol, vaginal examination
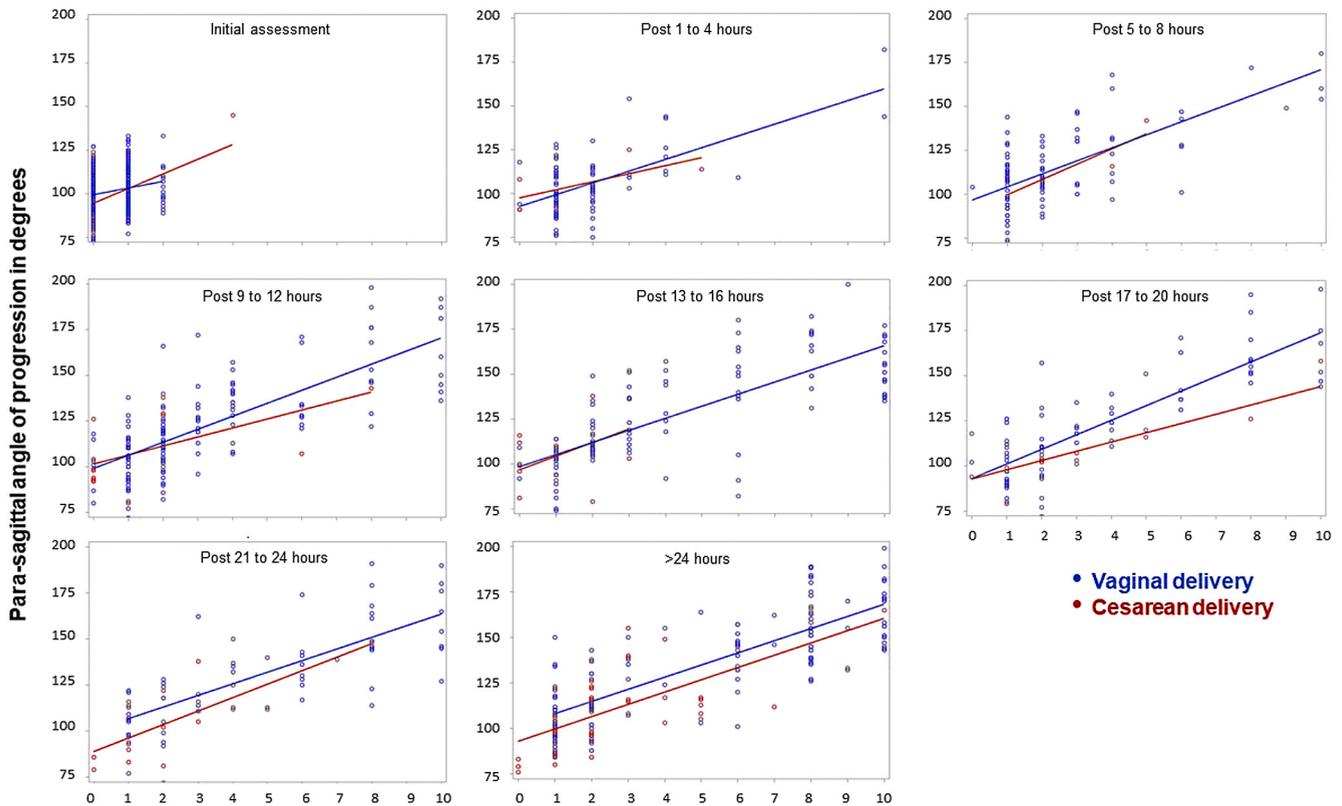
Changes in parasagittal angle of progression against fetal head station
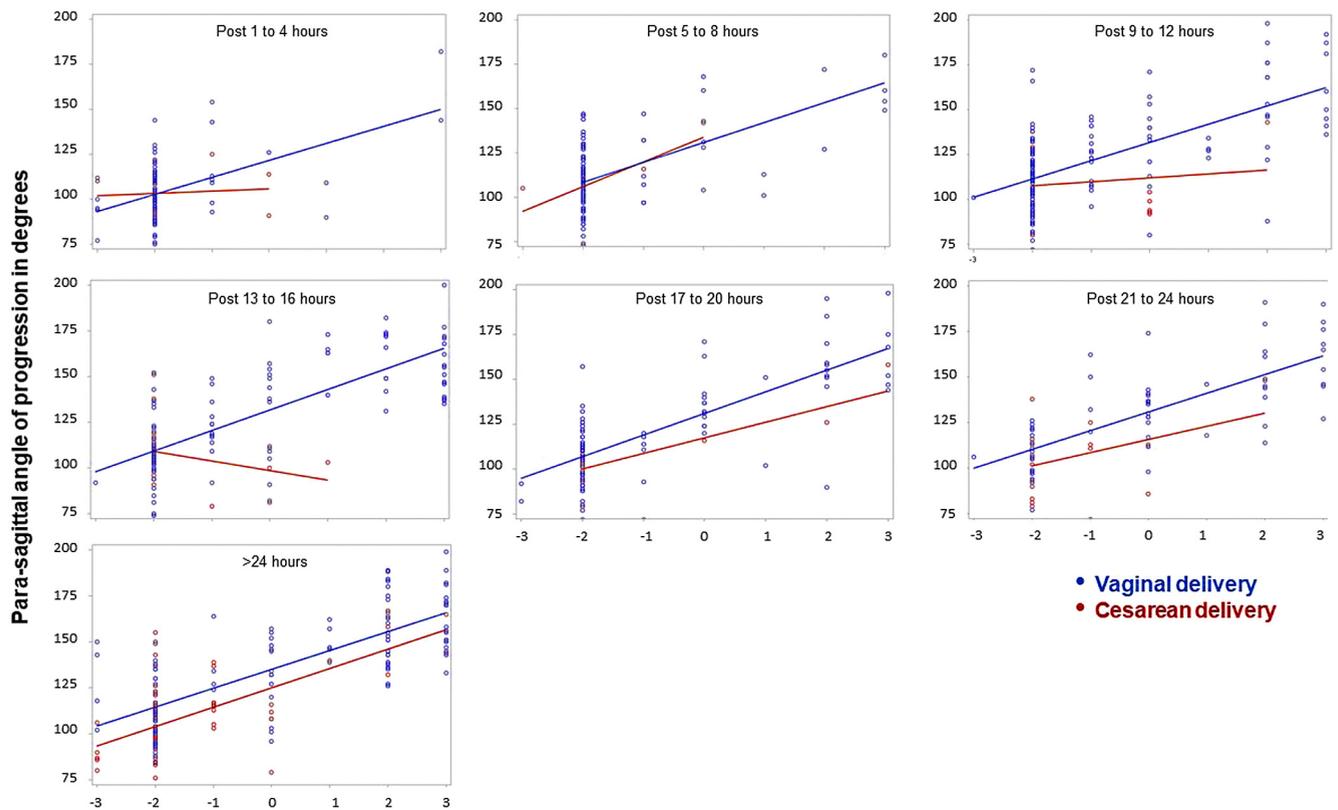
Changes in parasagittal angle of progression against fetal head station between women who require cesarean delivery (*red line*) and women who achieve vaginal delivery (*blue line*) taking into account of repeated measures from individuals.

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FIGURE 2
Changes in parasagittal angle of progression against cervical dilation

Changes in parasagittal angle of progression against cervical dilation between women who require cesarean delivery (*red line*) and women who achieve vaginal delivery (*blue line*) taking into account of repeated measures from individuals.

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was performed every 24 hours during latent phase and every 4 hours during active phase of labor.

The ultrasound assessment was not used to guide clinical management, and the clinical team attending to the participant during the induction of labor was not made aware of the transperineal ultrasonographic findings.

TABLE 3
Association between parasagittal angle of progression and head-perineum distance against fetal head station controlling for confounders

Variable	Parasagittal angle of progression		Head-perineum distance	
	Estimate (standard error)	P value[a]	Estimate (standard error)	P value[a]
Fetal head station	11.4 (0.35)	<.01	−0.50 (0.02)	<.01
Cesarean delivery	−15.4 (2.80)	<.01	0.69 (0.16)	<.01
Fetal head station and cesarean delivery	−5.11 (1.15)	<.01	0.27 (0.07)	<.01
Obesity	−2.41 (1.95)	.22	0.33 (0.11)	<.01
Use of Propess[b]	−2.41 (1.93)	.21	0.18 (0.11)	.12
Nulliparity	6.12 (2.01)	<.01	−0.18 (0.12)	.12
Epidural anesthesia	−2.64 (3.45)	.44	0.05 (0.20)	.80

[a] Statistically significant at P<.05; [b] Ferring Pharmaceuticals, Saint-Prex, Switzerland.

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TABLE 4
Association between parasagittal angle of progression and head-perineum distance against cervical dilation controlling for confounders

Variable	Parasagittal angle of progression		Head-perineum distance	
	Estimate (standard error)	P value[a]	Estimate (standard error)	P value[a]
Cervical dilation	7.10 (0.15)	<.01	−0.30 (0.01)	<.01
Cesarean delivery	−2.90 (1.99)	.15	−0.03 (0.13)	.81
Cervical dilation and cesarean delivery	−1.37 (0.51)	.01	0.12 (0.03)	<.01
Obesity	−2.59 (1.54)	.09	0.33 (0.10)	<.01
Use of Propess[b]	−1.56 (1.51)	.31	0.07 (0.10)	.48
Nulliparity	5.84 (1.55)	<.01	−0.11 (0.10)	.26
Epidural anesthesia	−1.12 (2.75)	.96	0.02 (0.18)	.89

[a] Statistically significant at $P<.05$; [b] Ferring Pharmaceuticals, Saint-Prex, Switzerland.

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The researchers were blinded to the findings of the clinical team's vaginal examination.

Maternal characteristics that included age, weight, height, parity, gestational age, method of induction of labor, use of epidural anesthesia, and ultrasound findings were recorded in a secured electronic database. Obesity was defined as body mass index of ≥ 30 kg/m^2.[54] Gestational age was determined from the first date of the last menstrual period and confirmed by the measurement of crown-rump length in the first trimester or head circumference in the second trimester. The primary endpoint of the study was cesarean delivery.

Induction of labor
Induction of labor was performed according to the standardized management protocol of the hospital. The Bishop score was determined by an experienced obstetrician. Labor was induced with amniotomy followed by oxytocin, if the cervix was favorable (Bishop score >6). If the cervix was unfavorable, labor was induced with 10-mg dinoprostone slow-release vaginal pessary (Propess; Ferring Pharmaceuticals, Saint-Prex, Switzerland). In women with previous cesarean delivery, intracervical balloon (Cook Cervical Ripening balloon; Cook Medical LLC, Bloomington, IN) was used. The women with unfavorable cervix were reassessed 24 hours later; if the cervix remained unfavorable, a further 10 mg of Propess was given, and if the cervix was favorable amniotomy was carried out. If the woman remained in latent phase after 12 hours of oxytocin infusion or if there were ≥ 2 episodes that the cervix failed to dilate at a rate of 1 cm per hour when the cervix was >3 cm dilated, a cesarean delivery was indicated because of no progress of labor. Data on pregnancy and labor outcomes were retrieved from computerized medical records and were recorded in the database.

Statistical analysis
The repeated measures data were analyzed by mixed effect models. In the models, covariance structures of intra-individual measurements were assumed to capture the correlations of changes in psAOP and HPD over time. To determine the effect of mode of delivery (vaginal delivery vs cesarean delivery) on the association between psAOP and HPD against fetal head station and cervical dilation, the significance of the interaction term between each mode of delivery and fetal head station or cervical dilation was determined, controlling for obesity, parity, methods of labor induction, and epidural anesthesia. Likelihood ratio tests were used to test the global fitness of the mixed effect models. To assess the performance of psAOP and HPD in the prediction of the mode of delivery (vaginal delivery vs cesarean delivery), multivariate logistic regression analysis was used to account for factors that affected ultrasound-determined labor progress. Based on the findings in our recent publication,[53] the temporal changes of psAOP

TABLE 5
Association between parasagittal angle of progression and fetal head station in the subgroups of nulliparity and multiparity controlling for confounders

Variable	Nulliparity		Multiparity	
	Estimate (standard error)	P value[a]	Estimate (standard error)	P value[a]
Fetal head station	11.5 (0.41)	<.01	11.4 (0.69)	<.01
Cesarean delivery	−13.9 (3.06)	<.01	−31.0 (8.94)	<.01
Fetal head station and cesarean delivery	−5.28 (1.19)	<.01	−6.63 (4.33)	.13
Obesity	−2.70 (2.51)	.29	−1.50 (3.11)	.63
Use of Propess[b]	−2.67 (2.35)	.26	−2.14 (3.55)	.55
Epidural anesthesia	−3.31 (3.65)	.37	22.7 (17.0)	.19

[a] Statistically significant at $P<.05$; [b] Ferring Pharmaceuticals, Saint-Prex, Switzerland.

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Variable	Nulliparity		Multiparity	
	Estimate (standard error)	P value[a]	Estimate (standard error)	P value[a]
Cervical dilation	7.17 (0.17)	<.01	6.97 (0.30)	<.01
Cesarean delivery	−1.57 (2.20)	.48	−9.17 (5.11)	.08
Cervical dilation and cesarean delivery	−1.54 (0.51)	<.01	−1.05 (2.26)	.64
Obesity	−3.01 (1.99)	.13	−1.71 (2.48)	.49
Use of Propess[b]	−2.09 (1.84)	.26	−0.60 (2.75)	.83
Epidural anesthesia	−0.01 (2.87)	.99	5.37 (13.7)	.70

[a] Statistically significant at $P<.05$; [b] Ferring Pharmaceuticals, Saint-Prex, Switzerland.

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(or HPD) per unit change of fetal head station (or cervical dilation) were determined by averaging the ratio of change between psAOP (or HPD) and fetal head station (or cervical dilation) in all measured time periods for individual level prediction. Area under receiver-operating characteristic curve (AUROC) was used to evaluate the

FIGURE 3
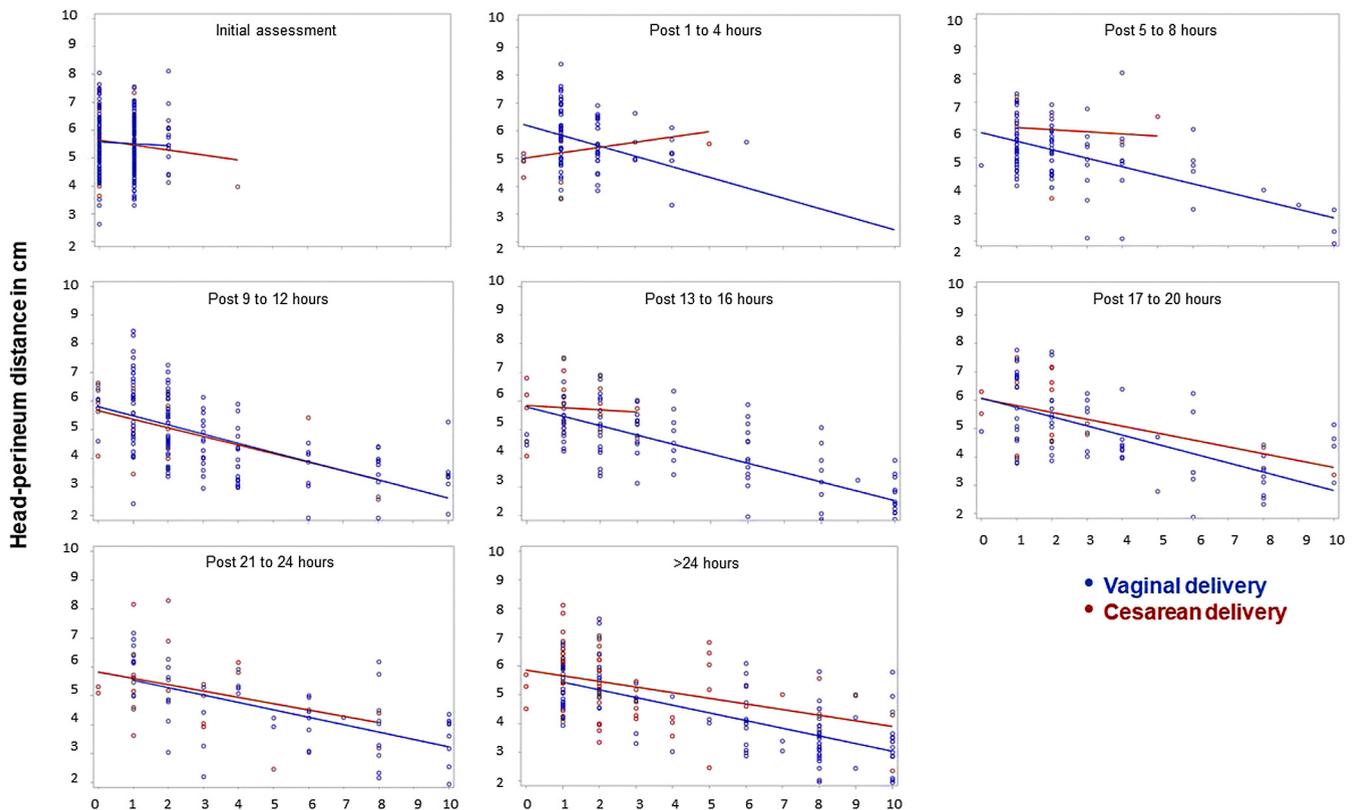**Changes in head-perineum distance against fetal head station**
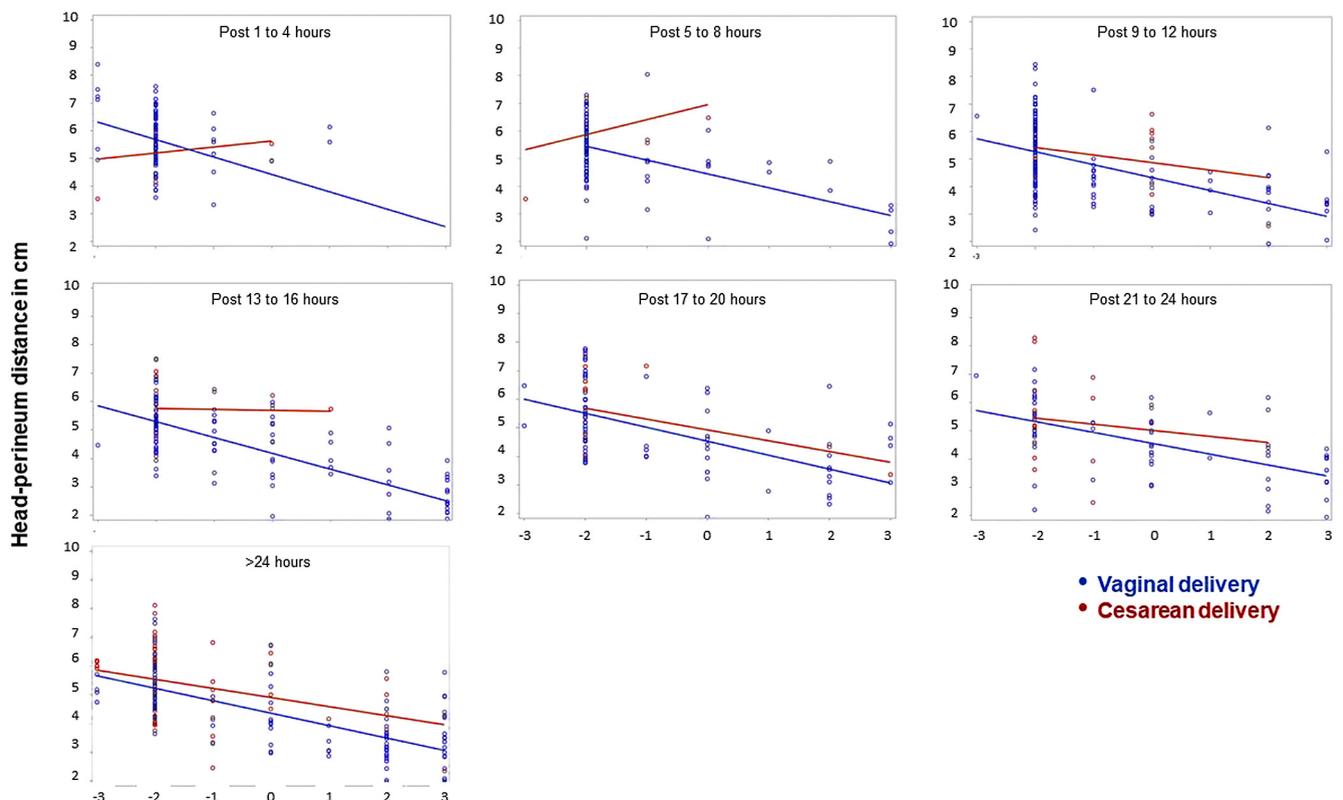
Changes in head-perineum distance against fetal head station between women who require cesarean delivery (*red line*) and women who achieve vaginal delivery (blue line) taking into account of repeated measures from individuals.

cm, centimeter.

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FIGURE 4
Changes in head-perineum distance against cervical dilation

Changes in head-perineum distance against cervical dilation between women who require cesarean delivery (*red line*) and women who achieve vaginal delivery (*blue line*) taking into account of repeated measures from individuals.

cm, centimeter.

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performance of serial intrapartum sonography in the prediction of women with cesarean delivery and with cesarean delivery because of failure to progress. Statistical analysis was performed with the SAS software system (version 9.4; SAS Institute Inc, Cary, NC).

Results
Maternal characteristics
Three hundred forty-five pregnant women were recruited. We excluded 30 cases because of incomplete data in 27 cases; 3 women went into labor before the induction of labor. Of the remaining 315 cases, 261 women (82.9%) achieved vaginal delivery, and 54 women (17.1%) required cesarean delivery. The indications for cesarean delivery were failed induction or failure to progress (n=32; 59.3%), chorioamnionitis (n=12; 22.2%), fetal distress (n=6; 11.1%), and abnormal presentation (n=4; 7.4%). Characteristics of the study population are presented in Table 1. In the cesarean

TABLE 7
Association between head-perineum distance and fetal head station in the subgroups of no obesity and obesity controlling for confounders

Variable	No obesity		Obesity	
	Estimate (standard error)	*P* value[a]	Estimate (standard error)	*P* value[a]
Fetal head station	−0.48 (0.02)	<.01	−0.55 (0.04)	<.01
Cesarean delivery	0.81 (0.21)	<.01	0.55 (0.24)	.03
Fetal head station and cesarean delivery	0.30 (0.09)	<.01	0.28 (0.11)	.01
Use of Propess[b]	0.14 (0.13)	.29	0.19 (0.22)	.39
Nulliparity	−0.20 (0.14)	.15	−0.08 (0.23)	.74
Epidural anesthesia	−0.14 (0.25)	.57	0.46 (0.31)	.15

[a] Statistically significant at *P*<.05; [b] Ferring Pharmaceuticals, Saint-Prex, Switzerland.

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delivery group, compared with the vaginal delivery group, the median age and body mass index were significantly higher; the median height and Bishop score were significantly lower; there were more nulliparous women and more women who needed Propess for labor induction and the use of epidural anesthesia. The labor duration, induction-to-delivery interval, and arterial blood gas pH were significantly lower in women who achieved vaginal delivery than those who required cesarean delivery (Table 1).

Paired vaginal examination and transperineal ultrasound assessment

After the commencement of induction of labor, the total number of paired vaginal examination and transperineal ultrasonographic assessments was 1198, with a median of 3 (interquartile range, 2−4) per woman. The median assessment-to-assessment interval was 4.6 hours (interquartile range, 4.3−5.1).

Ultrasound-determined labor progress vs mode of delivery
Changes in psAOP

Mode of delivery was significantly affecting the association between psAOP against fetal head station and cervical dilation, taking account of repeated measures from individuals; vaginal delivery had steeper slopes of psAOP against fetal head station and cervical dilation. Objectively, an additional decrease of 5.28 degrees and 1.35 degrees in psAOP was observed, for an unit increase in fetal head station and cervical dilation, respectively, in women who required cesarean delivery ($P<.01$; $P=.01$), compared with women who achieved vaginal delivery (Table 2; Figures 1 and 2). Accounting for confounders, vaginal delivery remained to have steeper slopes of psAOP against fetal head station and cervical dilation. The respective additional decrease in psAOP for an unit increase in fetal head station and cervical dilation were 5.11 degrees ($P<.01$) and 1.37 degrees ($P=.01$),in women who required cesarean delivery, which accounted for all

confounders ($P<.01$; Tables 3 and 4; Supplemental Figures 1 and 2).

The changes in psAOP against fetal head station and cervical dilation according to the mode of delivery in the subgroups of nulliparity and multiparity are given in Tables 5 and 6.

Changes in head-perineum distance
Mode of delivery was significantly affecting the association between HPD against fetal head station and cervical dilation, taking account of repeated measures from individuals; vaginal

TABLE 8
Association between head-perineum distance and cervical dilation in the subgroups of no obesity and obesity controlling for confounders

Variable	No obesity		Obesity	
	Estimate (standard error)	P value[a]	Estimate (standard error)	P value[a]
Cervical dilation	−0.28 (0.01)	<.01	−0.34 (0.02)	<.01
Cesarean delivery	0.14 (0.16)	.40	−0.49 (0.21)	.02
Cervical dilation and cesarean delivery	0.11 (0.04)	.01	0.17 (0.06)	<.01
Use of Propess[b]	0.04 (0.11)	.73	0.14 (0.19)	.45
Nulliparity	−0.17 (0.12)	.16	0.08 (0.19)	.69
Epidural anesthesia	−0.17 (0.22)	.44	0.42 (0.27)	.13

[a] Statistically significant at $P<.05$; [b] Ferring Pharmaceuticals, Saint-Prex, Switzerland.

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TABLE 9
Performance of maternal characteristics and serial transperineal sonography for the prediction of women who will require cesarean delivery

Variable	Area under receiver-operating characteristic curve (95% confidence interval)	Sensitivity (%) at 80% specificity	P value[a]
Per unit change of cervical dilation			
Parasagittal angle of progression	0.79 (0.72−0.87)	71	<.01
Head-perineum distance	0.79 (0.71−0.87)	66	<.01
Parasagittal angle of progression and head-perineum distance	0.80 (0.72−0.88)	71	<.01
Per unit change of fetal head station			
Parasagittal angle of progression	0.87 (0.80−0.93)	77	<.01
Head-perineum distance	0.77 (0.68−0.87)	59	<.01
Parasagittal angle of progression and head-perineum distance	0.87 (0.80−0.93)	82	<.01

[a] Likelihood ratio test for model fitness.

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TABLE 10
Performance of maternal characteristics and serial transperineal sonography for the prediction of women who will require cesarean delivery because of failure to progress of labor

Variable	Area under receiver-operating characteristic curve (95% confidence interval)	Sensitivity (%) at 80% specificity	P value[a]
Per unit change of cervical dilation			
Parasagittal angle of progression	0.79 (0.70—0.88)	67	<.01
Head-perineum distance	0.78 (0.68—0.88)	70	<.01
Parasagittal angle of progression and head-perineum distance	0.80 (0.71—0.89)	67	<.01
Per unit change of fetal head station			
Parasagittal angle of progression	0.85 (0.76—0.94)	79	<.01
Head-perineum distance	0.74 (0.62—0.87)	57	.08
Parasagittal angle of progression and head-perineum distance	0.85 (0.76—0.94)	79	<.01

[a] Likelihood ratio test for model fitness.

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delivery had steeper slopes of HPD against fetal head station and cervical dilation than did cesarean delivery. Objectively, an additional increase of 0.27 cm and 0.12 cm in HPD was observed, for a unit increase in fetal head station and cervical dilation, respectively, in women who required cesarean delivery (P<.01; P<.01), compared with women who achieved vaginal delivery (Table 2; Figures 3 and 4). Accounting for confounders, vaginal delivery remained to have steeper slopes of HPD against fetal head station and cervical dilation. The respective additional increase in HPD for an unit increase in fetal head station and cervical dilation were 0.27 cm (P<.01) and 0.12 cm (P<.01) in women who required cesarean delivery (Tables 3 and 4; Supplemental Figures 3 and 4).

The changes in HPD against fetal head station and cervical dilation according to the mode of delivery in the subgroups of no obesity and obesity are given in Tables 7 and 8.

Predictive performance of serial intrapartum transperineal ultrasound

For the prediction of women who required cesarean delivery, a combination of maternal characteristics with either psAOP or HPD per unit change of cervical dilation both achieved an AUROC of 0.79 (P<.01; Table 9). A combination of maternal characteristics with both ultrasound parameters per unit change of cervical dilation achieved an AUROC of 0.80 (P<.01). The AUROCs of a combination of

FIGURE 5
Receiver-operating characteristic curve for the prediction of cesarean delivery because of failure to progress in labor
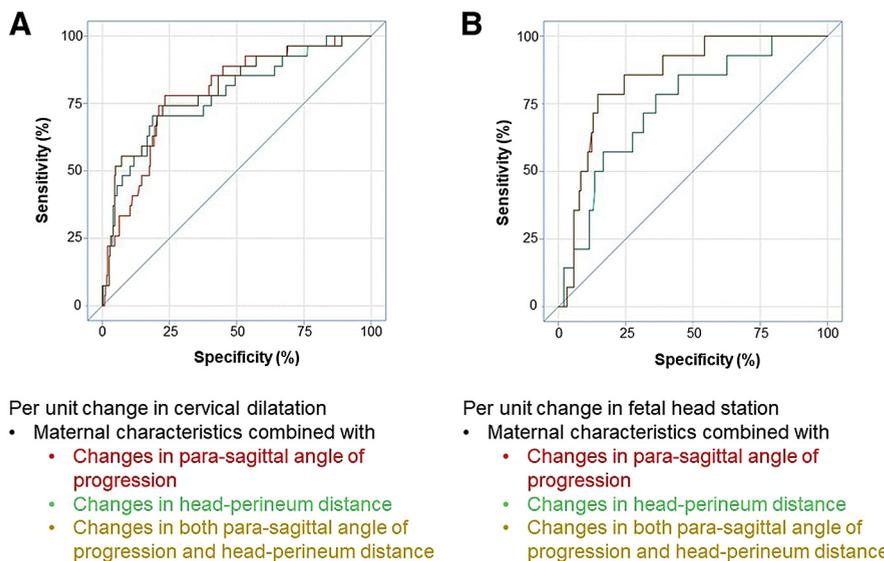

A, Maternal characteristics combined with temporal changes in parasagittal angle of progression (*red line*), head-perineum distance (*green line*), or the combination of both ultrasound parameters (*brown line*) when determined against per unit change in cervical dilation. B, Maternal characteristics combined with temporal changes in parasagittal angle of progression (*red line*), head-perineum distance (*green line*), or the combination of both ultrasound parameters (*brown line*) when determined against per unit change in fetal head station.

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FIGURE 6

Serial measurements of parasagittal angle of progression from the commencement of induction of labor in a case of cesarean delivery for failure to progress in labor
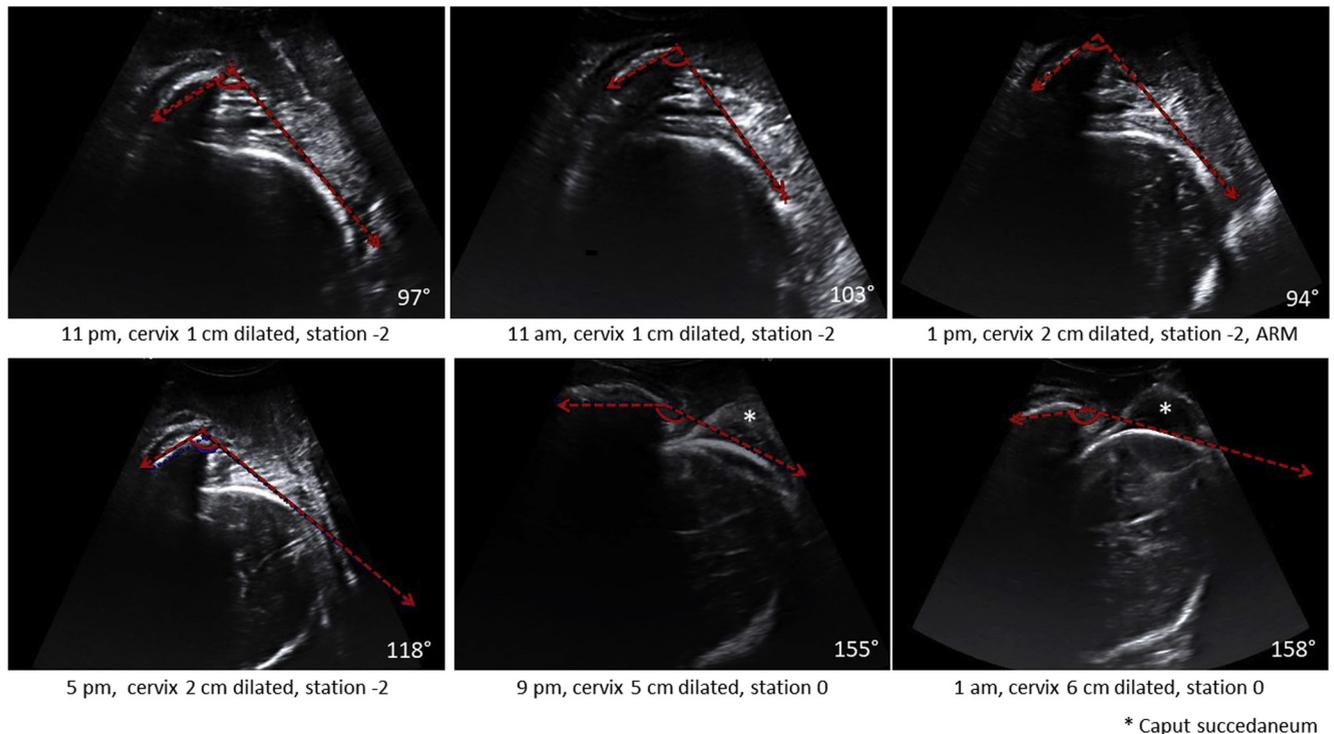
Serial measurements of parasagittal angle of progression from the commencement of induction of labor until cesarean delivery for failure to progress in labor. The *asterisk* indicates caput succedaneum.

ARM, artificial rupture of the membranes; *cm*, centimeter.

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maternal characteristics with either psAOP or HPD per unit change of fetal head station were 0.87 and 0.77 (both *P*<.01), respectively. The addition of HPD to the combination of maternal characteristics and psAOP did not improve the AUROC (Table 9).

For the prediction of women who required cesarean delivery for failure to progress (n=32), a combination of maternal characteristics with either psAOP or HPD per unit change of cervical dilation achieved AUROCs of 0.79 and 0.78 (both *P*<.01), respectively (Table 10, Figure 5). A combination of maternal characteristics with both ultrasound parameters per unit change of cervical dilation achieved an AUROC of 0.80 (*P*<.01). The AUROCs of a combination of maternal characteristics with either psAOP or HPD per

unit change of fetal head station were 0.85 (*P*<.01) and 0.74 (*P*=.08), respectively. The addition of HPD to the combination of maternal characteristics and psAOP did not improve the AUROC (Table 10; Figure 5).

Figures 6 to 9 illustrate serial measurements of psAOP and HPD from the commencement of induction of labor in women who require cesarean delivery.
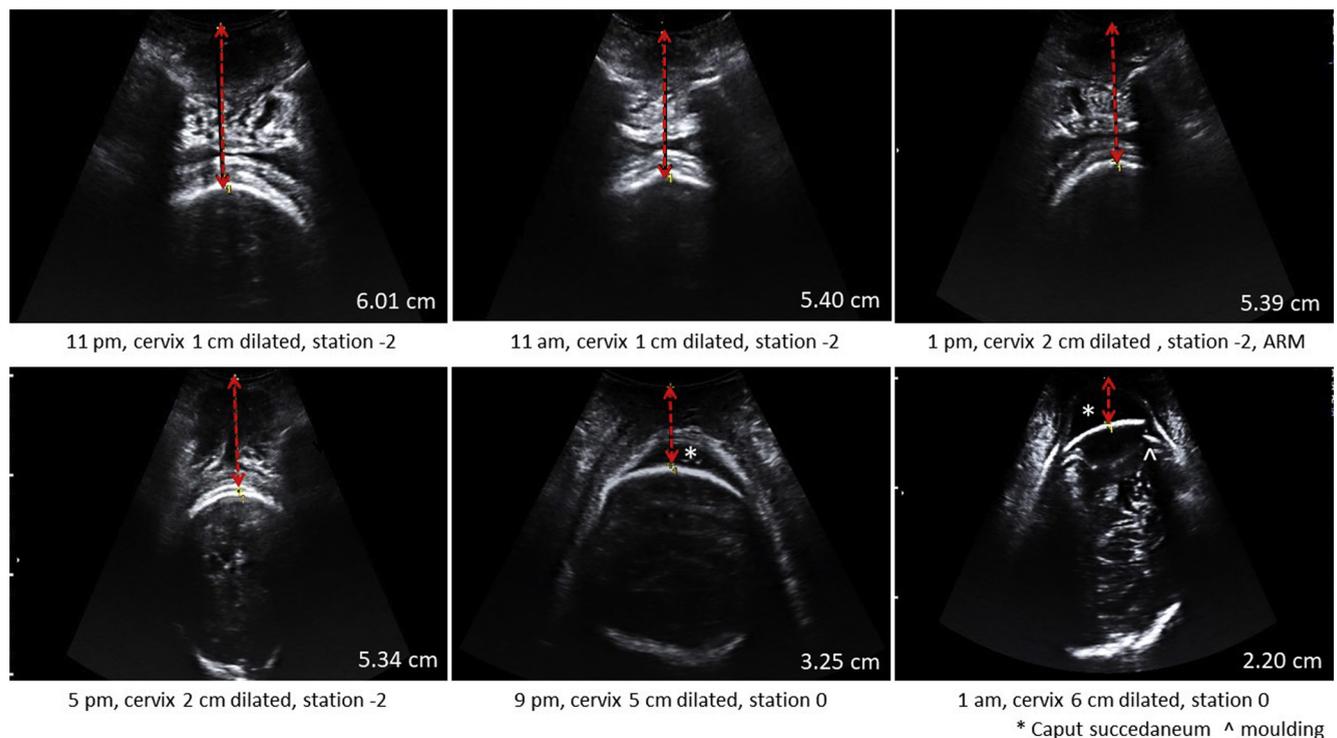
Comment
Principal findings of the study
With regard to the labor progress defined by transperineal ultrasonographic assessment of fetal head station, women who require cesarean delivery have a slower rate of fetal head descent, as represented by both psAOP and HPD against fetal head station and cervical dilation, than do women who

achieve vaginal delivery. Objectively, an additional decrease of 5.11 degrees and 1.37 degrees in psAOP for an unit increase in fetal head station and cervical dilation, respectively, and an additional increase of 0.27 cm and 0.12 cm in HPD for an unit increase in fetal head station and cervical dilation, respectively, are observed in women who require cesarean delivery, after accounting for confounders that include parity, obesity, methods of induction, and the use of epidural anesthesia. The combination of maternal characteristics and the temporal changes of psAOP per unit change of fetal head station achieves an AUROC of 0.85 for the prediction of women who require cesarean delivery because of failure to progress; the addition of HPD does not improve the AUROC.

FIGURE 7

Serial measurements of head-perineum distance from the commencement of induction of labor in a case of cesarean delivery for failure to progress in labor

6.01 cm — 11 pm, cervix 1 cm dilated, station -2

5.40 cm — 11 am, cervix 1 cm dilated, station -2

5.39 cm — 1 pm, cervix 2 cm dilated , station -2, ARM

5.34 cm — 5 pm, cervix 2 cm dilated, station -2

3.25 cm — 9 pm, cervix 5 cm dilated, station 0

2.20 cm — 1 am, cervix 6 cm dilated, station 0

* Caput succedaneum ^ moulding

Serial measurements of parasagittal angle of progression from the commencement of induction of labor until cesarean delivery for failure to progress in labor. The *asterisk* indicates caput succedaneum; the *circumflex accent mark* indicates moulding.

ARM, artificial rupture of the membranes; *cm*, centimeter.

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Results in context

This is the first and largest prospective longitudinal study to date to report on the temporal changes of psAOP and HPD throughout the first stage of labor and shows the significant differences in ultrasound-determined labor progress according to the 2 key modes of delivery: vaginal vs cesarean delivery. Our results are similar to those of previous studies[24] that have demonstrated a positive correlation between psAOP and fetal head station or cervical dilation and a negative correlation between HPD and fetal head station or cervical dilation throughout labor independent of the mode of delivery.[55–57] Unlike previous studies, which assessed only AOP and HPD as single measurements, we are able to demonstrate precisely the differences in the ultrasound-determined labor progress between vaginal and cesarean delivery according to psAOP and HPD per unit change of fetal head station and cervical dilation over time.

Our study shows that, after accounting for confounders parity, it is an independent factor that affects the association between psAOP and fetal head station or cervical dilation according to the different modes of delivery. In subgroup analysis, nulliparous women who require cesarean delivery have an additional decrease of 5.28 degrees and 1.54 degrees in psAOP, for an unit increase in fetal head station and cervical dilation, respectively; in multiparous women who require cesarean delivery, the respective additional decrease in psAOP is 6.63 degrees and 1.05 degrees; however, the latter does not achieve statistical significance because of the small number of cases (n=8). A clinical study of 4618 consecutive term spontaneous vaginal deliveries that used conventional digital vaginal examination in the determination of labor progress has shown that, in comparison with nulliparous women, multiparous women tend to have a higher fetal head station in the first stage of labor (cervical dilation, <6 cm) but faster fetal head descent since the beginning of labor until fetal head station at +2.[58] Other studies, in which the authors have used a robust statistical model to evaluate the fetal descent curves, have shown that multiparous women have higher fetal head station for a longer time before delivery, compared with nulliparous women.[59,60] Our study is different from the previous studies because we used a more objective approach in determining labor progress, and we did not aim to evaluate the different labor pattern between nulliparous and multiparous women.

FIGURE 8

Serial measurements of parasagittal angle of progression from the commencement of induction of labor in a case of cesarean delivery for failed induction of labor
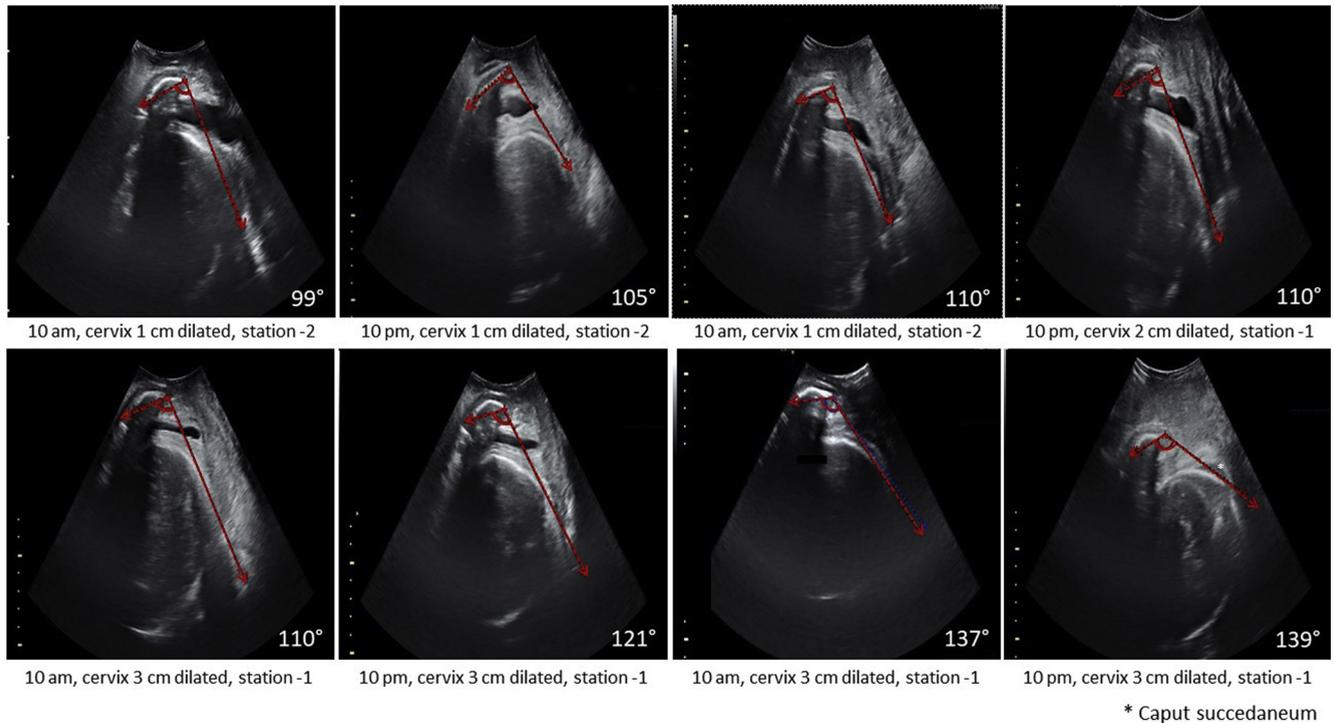
Serial measurements of parasagittal angle of progression from the commencement of induction of labor until cesarean delivery for failed induction of labor. The *asterisk* indicates caput succedaneum.

cm, centimeter.

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Obesity is known to be a risk factor for labor dystocia, but the underlying pathobiologic function is not well-understood.[61] The relationship between obesity and labor dystocia could be associated with delayed cervical ripening, reduced uterine myometrial oxytocin receptor expression, and myocyte dysfunction.[62,63] In our study, obesity has been found to be an independent factor that affects the association between HPD and fetal head station or cervical dilation, according to the different modes of delivery. In subgroup analysis, obese women who require cesarean delivery have an additional increase of 0.28 cm and 0.17 cm in HPD for an unit increase in fetal head station and cervical dilation, respectively; in non-obese women who require cesarean delivery, the respective additional increase in HPD is 0.30 cm and 0.11 cm. These findings imply a possible effect of the increased subcutaneous tissue over the perineum in obesity on the evaluation of ultrasound-determined labor progress. The method for the measurement of HPD, which is the shortest distance from the outer bony limit of fetal skull to skin surface of perineum by a transperineal ultrasound examination, requires compression of the soft tissue in the perineum with firm pressure without creating discomfort for the women. This could be a potential limitation with the use of HPD in the evaluation of labor progress in obese women. Nonetheless, further studies to investigate the relationship between obesity, fetal head station, and labor dystocia are warranted.

We have demonstrated that the combination of maternal characteristics and temporal changes of psAOP per unit change of fetal head station yields the best AUROC and sensitivity (80% at 80% specificity) for the prediction of cesarean delivery because of failure to progress. These observations are novel.

Clinical implications

The use of a partogram in active labor is recommended currently by the World Health Organization.[64] The World Health Organization prospective trial in South East Asia has reported that the use of a partogram is associated with a reduction in the rates of prolonged labor (from 6.4–3.4%), of labor that requires augmentation (from 20.7–9.1%), of emergency cesarean delivery (from 9.9–8.3%), and of intrapartum stillbirths (from 0.5–0.3%).[65] However, a Cochrane review has demonstrated that the evidence of the effectiveness of partogram is inconclusive because there are no differences in the rates of cesarean delivery, the use of oxytocin, the duration of first stage of labor, or an Apgar

FIGURE 9

Serial measurements of head-perineum distance from the commencement of induction of labor in a case of cesarean delivery for failed induction of labor
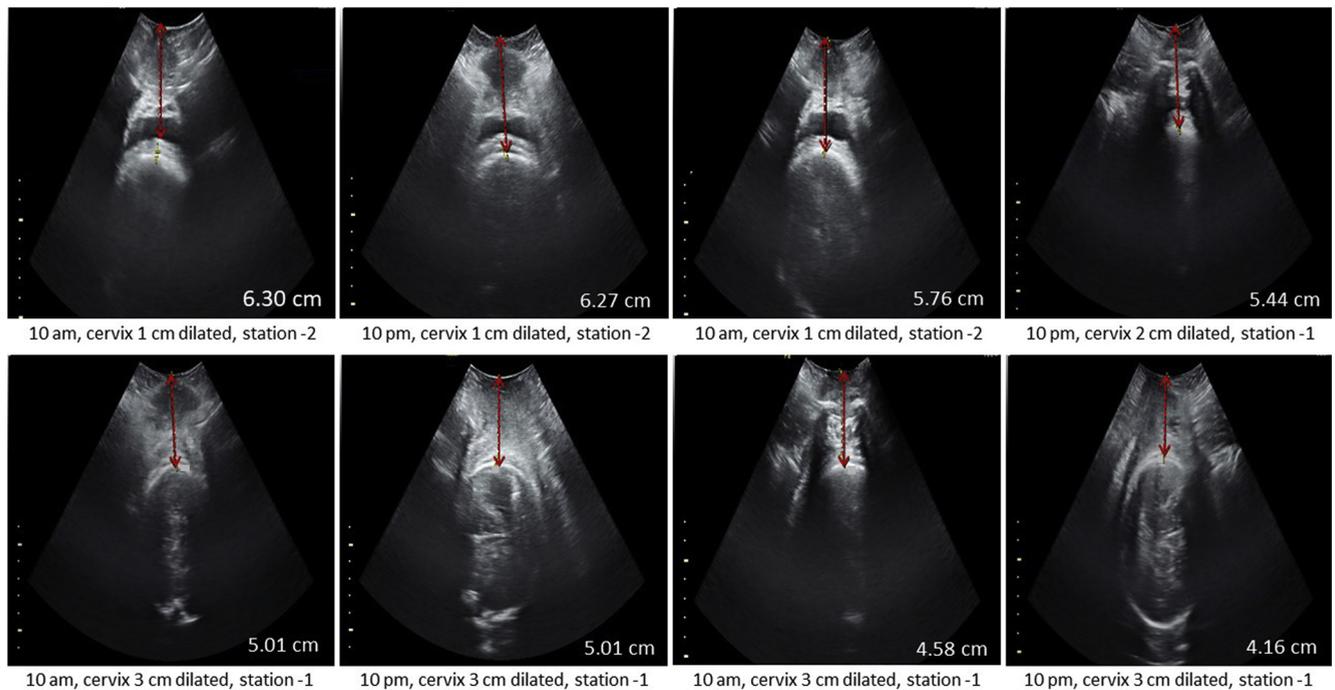
Serial measurements of head-perineum distance from the commencement of induction of labor until cesarean delivery for failed induction of labor.
cm, centimeter.

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score <7 at 5 minutes between the use of partogram and no partogram.[66] These findings suggest that there are some limitations of the partogram, which include imprecise determination of cervical dilation and lack of accurate timing of cervical dilation assessment.[67] Further, in current obstetric practice, the partogram is used to guide labor management irrespective of known factors that affect labor progress.[48,52,53]

Our study has demonstrated that serial transperineal ultrasound measurement of fetal head descent can be used to differentiate the labor progress between women who achieve a vaginal delivery and those who require a cesarean delivery. Parity and obesity are independent predictors of ultrasound-determined labor progress according to modes of delivery. Such findings potentially can guide clinicians to determine whether diagnosis of labor dystocia based on transperineal ultrasound of fetal head descent is due to these factors

and therefore to adjust management accordingly. In addition, serial measurements of psAOP achieve a sensitivity of 80% at 80% specificity for the prediction of women who require cesarean delivery because of failure to progress.

Research implications

Further research is required to replicate our results. In addition, future work is needed to evaluate whether transperineal ultrasonographic parameters of fetal head descent and known factors that affect labor progress can be incorporated within the existing partogram in a larger population[52] and demonstrate whether the integrated partogram can improve clinical outcomes in terms of reduced morbidity, improved safety, optimized use of resources, and improved satisfaction of women during labor and delivery.[68]

Strengths and limitations

Strengths of our study include (1) the conduct of a large prospective longitudinal

study that involved women with singleton pregnancy who underwent induction of labor at term, (2) repeated measurements of transperineal ultrasonographic parameters of fetal head station from the beginning of labor and throughout the first stage, (3) blinding of clinicians and researchers to each other's assessment to minimize bias, (4) objective assessment and quantification of labor progress by serial transperineal ultrasonographic assessment, and (5) an accounting for known factors that affect ultrasound-determined labor progress when the temporal changes of psAOP and HPD are being evaluated according to the modes of delivery.

Main limitations of this study are that our study population included mainly Chinese women who were undergoing labor induction because this would allow the evaluation of labor progress and acquisition of transperineal ultrasonographic parameters from the beginning of labor. Our results might not be

generalizable to other ethnic populations or represent labor progress in women with spontaneous onset of labor. Further, we combined cesarean deliveries for failed induction and failure to progress because of the small number of cases. Finally, our study population had a very low rate of epidural anesthesia (5.1%), which may raise concerns that our results are not applicable to other populations with higher epidural anesthesia rates.

Conclusions

In conclusion, we have demonstrated the differences in labor progress between women who achieve a vaginal delivery and those who require a cesarean delivery objectively by serial intrapartum transperineal ultrasonographic assessment of fetal head descent, accounting for known factors that affect labor progress that includes parity and obesity. This tool is potentially predictive of women who will require cesarean delivery because of failure to progress. ■

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SUPPLEMENTARY FIGURE 1
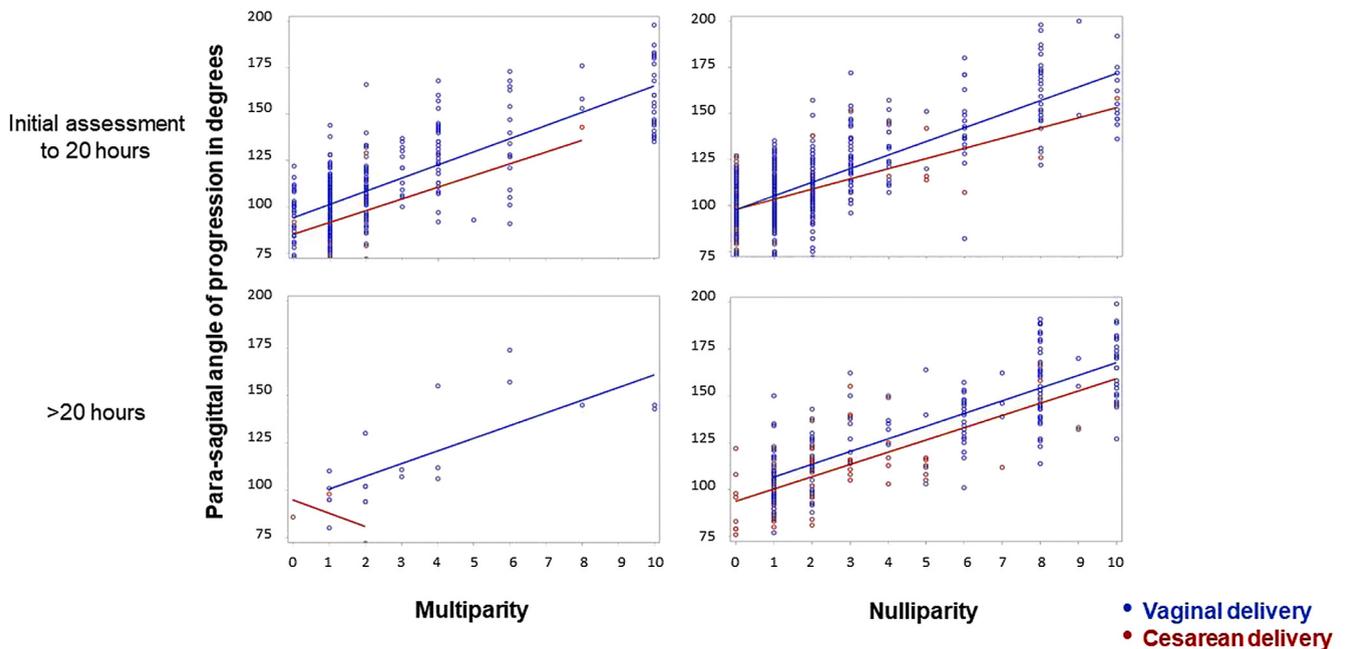**Changes in parasagittal angle of progression against fetal head station**
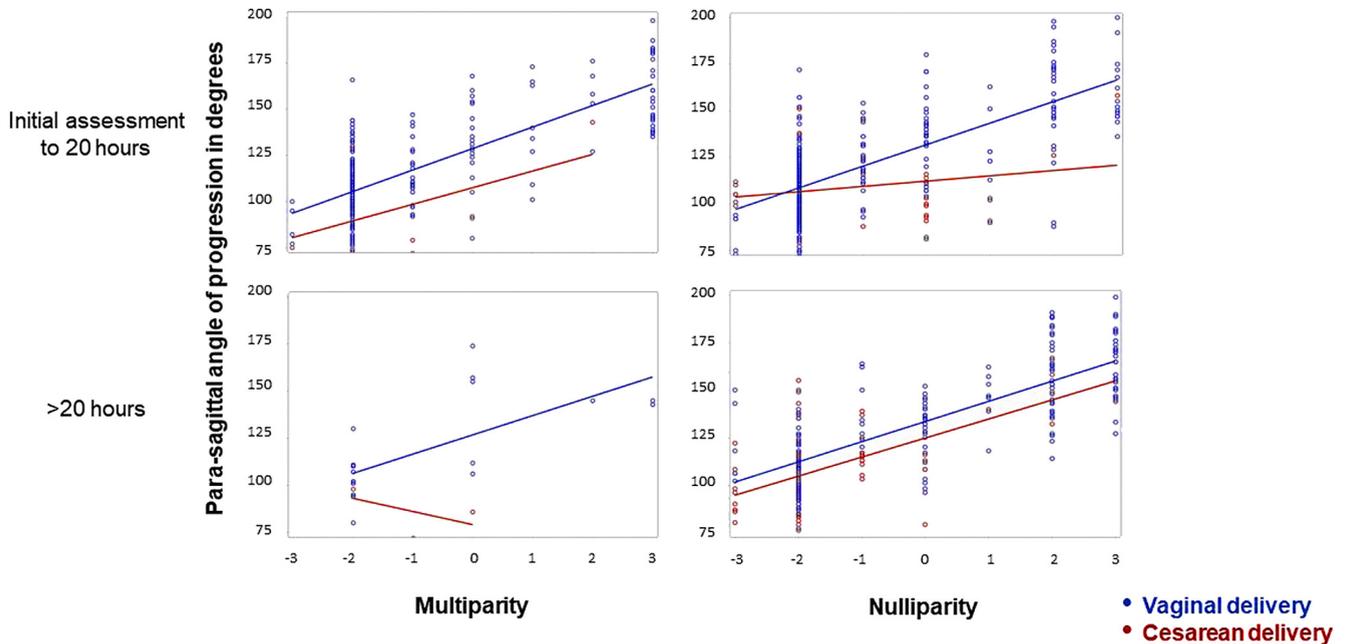
Changes in parasagittal angle of progression against fetal head station between women who require cesarean delivery (*red line*) and women who achieve vaginal delivery (*blue line*) in the subgroups of nulliparity and multiparity.

Tse et al. Ultrasound-determined labor progress according to modes of delivery. Am J Obstet Gynecol 2019.
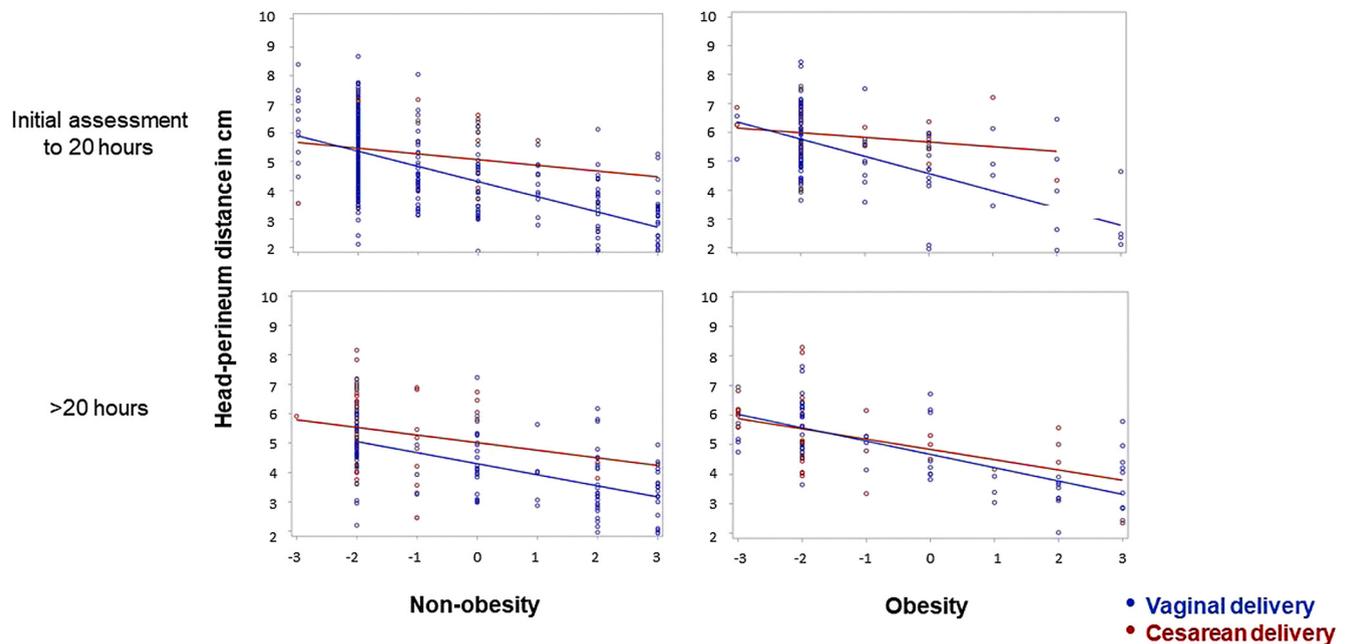

SUPPLEMENTARY FIGURE 2
Changes in parasagittal angle of progression against cervical dilation

Changes in parasagittal angle of progression against cervical dilation between women who require cesarean delivery (*red line*) and women who achieve vaginal delivery (*blue line*) in the subgroups of nulliparity and multiparity.

Tse et al. Ultrasound-determined labor progress according to modes of delivery. Am J Obstet Gynecol 2019.

SUPPLEMENTARY FIGURE 3
Changes in head-perineum distance against fetal head station
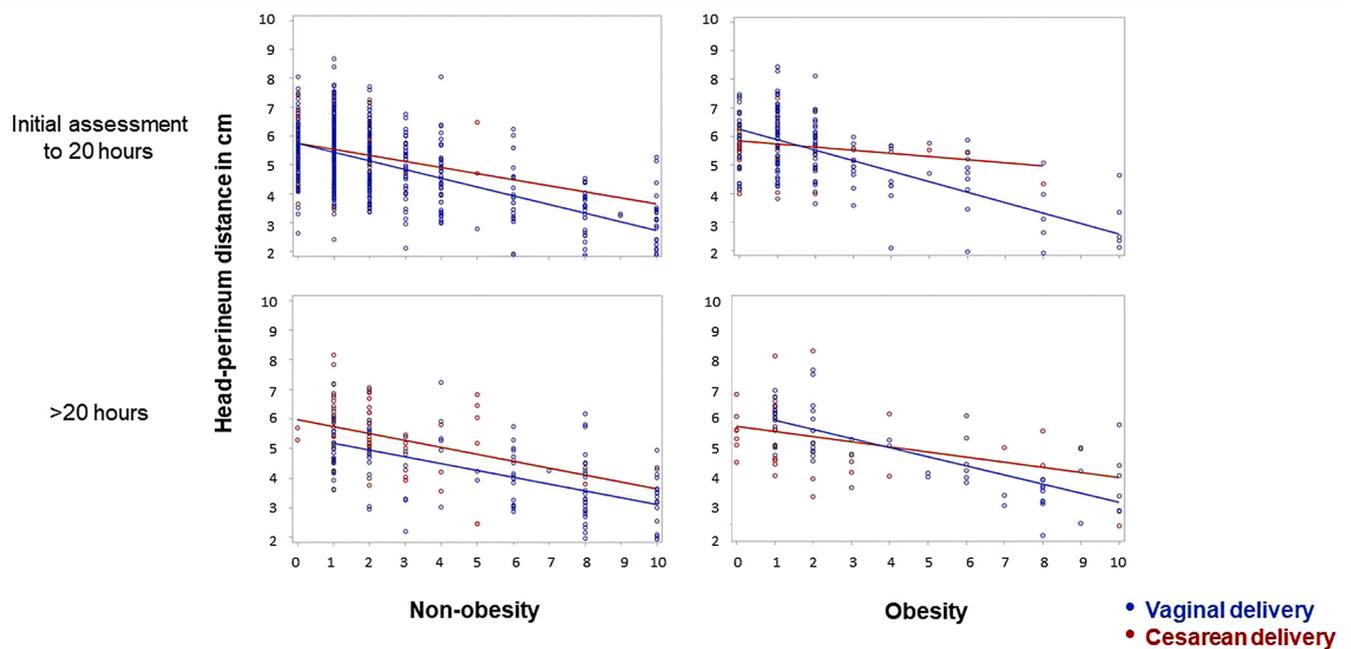

Changes in head-perineum distance against fetal head station between women who require cesarean delivery (*red line*) and women who achieve vaginal delivery (*blue line*) in the subgroups of no obesity and obesity.

cm, centimeter.

Tse et al. Ultrasound-determined labor progress according to modes of delivery. Am J Obstet Gynecol 2019.

SUPPLEMENTARY FIGURE 4
Changes in head-perineum distance against cervical dilation

Changes in head-perineum distance against cervical dilation between women who require cesarean delivery (*red line*) and women who achieve vaginal delivery (*blue line*) in the subgroups of no obesity and obesity.

cm, centimeter.

Tse et al. Ultrasound-determined labor progress according to modes of delivery. Am J Obstet Gynecol 2019.