Fetal descent in nulliparous women assessed by ultrasound: a longitudinal study

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Condensation

Transperineal ultrasound was used to follow fetal head descent longitudinally during the active phase in nulliparous women with spontaneous onset of labor at term.

Short Title

Fetal head descent in normal nulliparous women

AJOG at a Glance

A. ***Why was the study conducted***?
   - Clinical methods for assessing fetal head station are subjective and have limited accuracy
   - Ultrasound is an objective means for assessing fetal head station
   - To describe fetal head descent in nulliparous women with spontaneous labor onset

B. ***What are the key findings***?
   - Ultrasound assessed fetal stations at both the first and last examination were significantly associated with delivery mode
   - Both HPD of 30 mm and AoP of 125º independently predicted delivery in 3.0 hours (95% CI 2.5-3.8 and 2.4-3.7 hours, respectively)
   - Fetal head station remained unchanged early in the active phase of labor, but showed a pattern of rapid descent during the last four hours of labor, regardless of initial cervical dilatation or occiput position

C. ***What does this study add to what is already known***?
   - Ultrasound patterns for fetal head descent in nulliparous women were described

- Head-perineum distance and angle of progression predicted the remaining time to delivery
- Longitudinally measured head-perineum distance and angle of progression independently produced similar labor patterns

Structured Abstract

Background

Ultrasound offers objective and reproducible methods to measure fetal head station. Before these methods can be applied to assess labor progress, fetal head descent needs to be evaluated longitudinally in well-defined populations and compared to existing data derived from clinical examinations.

Objective

We aimed to use ultrasound measurements to describe fetal head descent longitudinally as labor progressed through the active phase in nulliparous women with spontaneous onset of labor.

Study Design

This was a single center, prospective cohort study at Landspitali University Hospital, Reykjavik, Iceland, from January 2016 to April 2018. Nulliparous women with a single fetus in cephalic presentation, spontaneous labor onset at gestational age ≥37 weeks were eligible. Inclusion occurred on admission for women with an established active phase of labor or at the start of the active phase in women admitted in the latent phase. Active phase was defined as an effaced cervix dilated at least four cm in women with regular contractions. According to clinical protocol vaginal examinations were done at entry and subsequently through labor, paired each time with a transperineal ultrasound examination by a separate examiner, both examiners being blinded to the other´s results. Measurements used to assess fetal head station were head-perineum distance and angle of progression. Cervical dilatation was examined clinically.

Results

The study population comprised 99 women. Labor patterns for head-perineum distance, angle of progression and cervical dilatation differentiated into 75 spontaneous , 16 instrumental

vaginal and eight cesarean deliveries are presented in the figure. At inclusion cervix was dilated four cm in 26, five cm in 30 and ≥ six cm in 43 women. One cesarean and one ventouse delivery were performed for fetal distress, the remaining due to failure to progress. The total number of examinations was 345, on average 3.6 per woman. Ultrasound measured station both at the first and last examination were associated with delivery mode and remaining time in labor. In spontaneous deliveries rapid head descent started around four hours before birth, the descent being more gradual in instrumental deliveries and absent in cesarean deliveries (Figure). Head-perineum distance of 30 mm and angle of progression of 125° separately predicted delivery in 3.0 hours (95% CI for 2.5-3.8 hours and 2.4-3.7 hours respectively) in women delivering vaginally. Head-perineum distance and angle of progression are independent methods, but gave similar mirror image patterns. The fetal head station at the first examination was highest for fetuses in occiput posterior position, but the pattern of rapid descent was similar for all initial positions in spontaneously delivering women. Oxytocin augmentation was used in 41% of women; in these labors slower descent was noted. Descent was only slightly slower in the 62% of women with epidural analgesia. A non-linear relationship was observed between station and dilatation.

Conclusions

We have created ultrasound measured descent patterns for nulliparous women in spontaneous labor. The patterns resemble previously published patterns based on clinical vaginal examination. Ultrasound measured station was associated with delivery mode and remaining time in labor.

Abbreviations: OA, occiput anterior; OP, occiput posterior; LOT, left occiput transverse; ROT, right occiput transverse; HPD, head perineum distance; AoP, angle of progression; WHO, World Health Organization

Key words: Angle of progression, cesarean delivery, fetal head position, fetal head station, head perineum distance, transabdominal ultrasound, transperineal ultrasound

Introduction

Proper descent of the fetal head during labor is a prerequisite for vaginal delivery. How this progress is followed and assessed is fraught with difficulty, as the landmarks on the fetal head and in the pelvis can be hard to identify. Clinical vaginal examination is prone to considerable subjectivity by the individual examiner. The spinal plane is not an actual anatomic plane in the pelvis, but an imaginary plane with only two anatomic reference points, the ischial spines,[1] which are moreover not in the pelvic midline where the station of the fetal head is gauged. The leading bony reference point on the fetal head should be easier to determine, but the presence of molding and caput succedaneum can make the examiner erroneously consider the head to have descended to a lower level than actually true. Therefore, other methods have been suggested.[2-5]

Knowledge of fetal head descent during labor comes mainly from the classic series of studies by Friedman and coworkers in 1965,[6-8] describing the patterns of descent based on clinical digital estimation of the fetal head station in the pelvic cavity. This work was essential for the WHO partograph and WHO has until 2018 recommended the partograph with an alert line with one cm cervical dilatation/hour and an action line displaced four hours as suggested by Philpott et al.[9-12]

There has in recent years been a renewed focus on the progress of labor, revisiting the classic Friedman dilatation and descent curves[13-16] in the light of changes in obstetric practice and populations.[17-20] Less attention has been paid to descent of the fetal head than cervical dilatation, although this was an integral part of the labor curves presented by Friedman and his coworkers. Fetal station and position remain the qualities by which progress during the second stage are judged. Recent clinical studies of fetal head descent have been conducted to compute mathematical models relating cervical dilatation to fetal head station.[21-23] The patterns of descent from these studies were obtained and described using the accepted clinical methods. Ultrasound has been suggested as more objective and accurate method in assessing fetal head station and having the potential to replace clinical methods.[23-40] The aim of this study was to use ultrasound measurement methods to describe fetal head descent longitudinally through the active phase in nulliparous women with spontaneous onset of labor at term.

Materials and methods

We performed a prospective cohort study at Landspitali University Hospital, Reykjavík, Iceland, from January 2016 to April 2018. The study population comprised 100 nulliparous women with spontaneous onset of labor, a single fetus in cephalic presentation and pregnancy length ≥37 weeks included non-consecutively. The study population corresponded to the definition of Group 1 in the Robson ten-group classification system.[41] One woman withdrew her consent and was excluded. All women received oral and written information about the study on admission to the labor ward and written consent was obtained before inclusion. Inclusion occurred on admission for women with an established active phase of labor or at the start of the active phase in women admitted in the latent phase. Active phase was defined at the time of recruitment as a fully effaced cervix, dilated at least four centimeters (cm), in the presence of regular contractions in accordance with the actual WHO recommendations.[9,10] All examinations were performed as paired clinical and ultrasound examinations throughout labor. Two obstetricians trained in transperineal scanning did the ultrasound examinations shortly before or after the clinical assessments (within 15 minutes). Cervical dilatation was examined clinically. Ultrasound examiners and clinical staff were blinded to each other´s results. The ultrasound examiners were not involved in clinical decisions during the labors.

The midwife caring for the woman performed a clinical examination at recruitment and thereafter as clinically indicated in accordance with local hospital guidelines recommending vaginal examinations at least every four hours. If cervical dilatation was not satisfactory, crossing the WHO partogram action line, the first option to augment labor progress was to rupture the membranes in case they were intact with reassessment after two hours. On the diagnosis of slow progress with ruptured membranes, a low-dose oxytocin infusion was used with reassessment after four hours. With no change in dilatation after a period of four hours with adequate contractions cesarean delivery was considered. An examination was also performed if the woman felt the urge to push, or at the midwife´s discretion. No upper limit for duration of the active phase existed at the hospital, but the duration of the second stage for a nullipara should not be longer than four hours with or three hours without epidural analgesia. The active pushing phase should not be longer than two hours. Signs of fetal distress on CTG monitoring were investigated further with fetal scalp pH or lactate samples.

During each examination the midwife judged the cervical dilatation in cm, and station using the scale of -5 to +5 cm above and below the ischial spines. All ultrasound examinations were performed by two experienced ultrasound examiners (HH and SB) and the findings recorded on a separate sheet of paper. A Voluson *i* ultrasound machine (GE Medical systems, Zipf, Austria) with a 3.5-7.5- MHz 3D curved multifrequency transabdominal transducer was used for both transabdominal and transperineal scans.

The fetal head descent was assessed by transperineal ultrasound. The measurements obtained were head-perineum distance (HPD) and angle of progression (AoP). The HPD was measured in the frontal plane (transverse plane related to perineum) as the shortest distance from the transducer to the fetal skull (Figure 1 and Video-Clip 1). The soft tissue was compressed with the transducer until it met resistance against the pubic bone.[28, 42] The AoP was measured in the sagittal plane as the angle between the longitudinal axis of the pubic symphysis and a line from the inferior edge of the symphysis tangentially to the fetal head contour (Figure 2 and Video-Clip 2).[43]

Fetal head position was determined using both the transabdominal and the transperineal approach. The transabdominal examination was preferred whenever reference structures could be visualized. The position of the occiput was marked on a clock-face like graph with half-hourly markings. Fetal head position was categorized as occiput anterior (OA; ≥10 and ≤2 o'clock), left occiput transverse (LOT; >2 and <4 o'clock), occiput posterior (OP; ≥4 and ≤8 o'clock) and right occiput transverse (ROT; >8 and <10 o'clock) positions, as described previously by Akmal et al.[44, 45] The fetal spine, orbits, midline structures and choroid plexus were used to determine position. Epidural analgesia used at the hospital consisted of intermittent doses of bupivacaine 2.5 mg/ml and sufentanil 5µg/ml.

The main objective of the study was to describe labor patterns for HPD and AoP in nulliparous women and investigate whether they differed by delivery mode. Furthermore, to build prediction models to estimate the time to delivery by HPD and AoP for women who deliver vaginally.

All ultrasound measurements were done online in the labor room and stored on the ultrasound device. The results and summaries of the outcome of the labors were later transferred into a database using the REDCap electronic data capture tools hosted at the hospital.[46] The study was approved by the Landspitali Ethics Committee, reference no.

26/2015.

Statistical analysis

To establish the labor patterns, the time of delivery was used as a fixed reference point. From that point, time was calculated backwards. Labor curves, with 95% confidence intervals shaded, were constructed with a 4^{th} degree polynomial model for each of the measurement variables; cervical dilatation, HPD and AoP, for the whole group and also according to delivery mode, i.e. spontaneous, instrumental and cesarean delivery. For spontaneous deliveries labor curves were constructed according to both epidural use and oxytocin augmentation and stratified by fetal head position and cervical dilatation at the first examination. We compared the HPD and AoP measurements to cervical dilatation and time remaining to delivery for women delivering vaginally using a mixed effects model. For descriptive purposes we used an HPD measurement of 36 mm and an AoP of 116° as representing the mid-pelvic or spinal plane, based on previously published studies.[47, 48] The Shapiro-Wilk test for normality was used for the AoP and HPD measurements. The AoP measurements were not normally distributed so we estimated differences in median cervical dilatation, AoP and HPD by mode of delivery with the Kruskal-Wallis test. The correlation between HPD and AoP was estimated from Spearman´s correlation coefficient and also the correlation between clinical station and HPD and AoP respectively.

Data were analyzed with the statistical software package R Core Team (2018). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria (URL https://www.R-project.org/).

Results

Study population

The final study population comprised 99 women, 75 had a spontaneous delivery, 15 were delivered with vacuum extraction, one with forceps and eight with a cesarean delivery. At inclusion the cervix was dilated to four cm in 26, five cm in 30 and ≥ six cm in 43 women. Characteristics of the study population, differentiated by delivery mode, are given in Table 1. The mean duration of the active phase of labor for women with spontaneous delivery was 8.4 (95% CI; 7.3-9.4) hours, 10.5 (95% CI; 8.3-12.7) hours for instrumental deliveries and 14.3 (95% CI; 9.7-18.8) hours in cases ending with a cesarean delivery. A total of 345 paired examinations were done, varying from one to eight examinations for each woman depending on the length of labor, on average 3.6 examinations. Two women were only examined once, 97 were examined at least twice, 66 three times, 49 four times, 24 five times, 15 six times and three women had eight examinations. Six cesarean deliveries were performed due to arrest of dilatation, one for arrest of descent in the second stage and one for fetal distress during the second stage (after a prolonged first stage). Details of these labors are given in Supplementary Table 1. One ventouse delivery was performed due to fetal distress, the other instrumental deliveries were all performed after a prolonged second stage or arrest of descent.

Labor patterns

Figure 3 is a scatterplot illustrating the variation and mean change in HPD, AoP and cervical dilatation from inclusion to delivery. Figure 4 shows for the same data the pattern of descent differentiated into spontaneous, instrumental and cesarean deliveries. The patterns of descent show that the fetal head was on average stationed above the mid-pelvic plane, i.e. >36 mm for HPD and <116° for AoP during the early stages of the active phase, but began to descend just before full cervical dilatation was reached. In spontaneous deliveries we observed a steep and continuous descent represented by decreasing HPD measurements and increasing AoP measurements. The descent began on average at 7 cm dilatation, around six hours before birth and became more accelerated at around 8 cm dilatation, four hours before birth. A more gradual descent was seen in the labor curves for instrumental vaginal deliveries and virtually no descent in the cases ending with cesarean delivery. Individual descent curves for women with a spontaneous delivery are shown in Supplementary Figure 1, and illustrate the large individual variation.

The pattern of clinically assessed cervical dilatation shows a linear slope which was steepest for spontaneous deliveries and slightly less steep in the cases ending with instrumental vaginal deliveries (Figure 4). A similar slope tapering off and then stopping at a mean of 8 cm dilatation, around 4 hours before delivery, was seen in the cases ending with cesarean delivery. Individual dilatation curves are shown in Supplementary Figure 1.

Both HPD and AoP measurements at the first and last examination showed a higher fetal head station at the first and last measurement in women ending with an operative delivery, and more pronounced in women needing cesarean delivery (Table 2). Mixed effects models comparing cervical dilatation and the fetal station measurements of HPD and AoP in women delivering vaginally showed that the relationship was not linear and that a 2nd degree model had a better fit (*p* value for comparisons of 1st and 2nd degree models <0.001). At 8 cm dilatation the prediction for an HPD measurement was 40 mm (95% CI 39-42) and for AoP it was 106° (95% CI 104-108°). At full dilatation this model predicted the HPD to be 29 mm (95% CI 28-31mm) and the AoP to be 126° (95% CI 124-129°) (Supplementary Table 2).

Prediction of time remaining to delivery based on HPD and AoP values using mixed effect models showed that for women delivering vaginally an HPD measurement of 40 mm predicted delivery in 5.5. hours (95% CI 5.1-6.1 hours) and for AoP of 110° the corresponding values were 5.2 hours (95% CI 4.7-5.7 hours). HPD of 30 mm and AoP of 125° both predicted delivery in 3.0 hours (95% CI for HPD 2.5-3.8, for AoP 2.4-3.7 hours)

Detailed information is shown in Table 3.

Figure 5 illustrates HPD and AoP descent curves differentiated by ultrasound assessed fetal positions at the first measurement in the women who delivered spontaneously. The fetal head station was highest for fetuses in an OP position. The pattern of rapid descent was similar for all positions and seemed to occur around four hours before birth. Oxytocin augmentation was used in 41% of women and these women had a slower descent (Figure 6). Figure 7 shows the HPD and AoP descent patterns in women with the use of epidural analgesia. Descent was only slightly slower in the 62% of women with epidural analgesia. The descent patterns for women included with four to five cm dilatation were not different compared with those included at more advanced dilatation (Figure 8).

Head-perineum distance and angle of progression are independent methods but correlated (r = -0.80; p <0.001) and gave similar mirror image patterns. The correlation between clinically assessed fetal station and HPD was r=-0.75; p<0.001 and for AoP r=0.75; p<0.001. The association between clinically assessed station and ultrasound measurements is shown in Supplementary Figure 2.

Comment

Principal findings

This is the first study describing longitudinally assessed fetal head descent using ultrasound among nulliparous women in spontaneous labor. We were able to create curves for fetal head descent, stratified by mode of delivery and for spontaneous deliveries we created curves stratified by both occiput position and cervical dilatation at inclusion and for epidural use and oxytocin augmentation. We found a significant association between measuring AoP and HPD at the first and last examination and mode of delivery. AoP and HPD measurements could be used to predict time to vaginal delivery and we have related them to the degree of cervical dilatation. These results confirm the feasibility of following fetal head descent during labor by ultrasound.

Clinical significance

Reducing the number of vaginal examinations during labor is important, both because of the discomfort and pain associated with them and not least to reduce the risk of infection.[49, 50] Compared to clinical vaginal examinations, measuring HPD and AoP is easy, non-invasive, and causes little discomfort, as confirmed by acceptability studies.[51-54] Ultrasound images can be stored and used as an objective documentation. The idea of a sonopartogram has already been advanced.[55] Being able to predict both the outcome of labor and time remaining in labor is important for both the woman in labor and her care provider. By describing the labor patterns for AoP and HPD and the associations to mode of delivery, time remaining in labor and to cervical dilatation we have shown that transperineal ultrasound is a feasible method to follow the progress of labor and can complement clinical vaginal examinations.

Research implications

Friedman published the graphic analysis of labor in 1954 [13] and the patterns of cervical dilatation and fetal descent in 1965.[6-8] Although Friedman considered both cervical dilatation and fetal descent of equal clinical importance there has since been a universal emphasis on following labor progress based on assessments of cervical dilatation in preference to fetal head descent. Vaginal delivery requires full cervical dilatation, but it is equally important for fetal head descent to be achieved down to the pelvic floor. Labor moreover does not end at full dilatation. Clinical palpation of the fetal head station is subjective and has limited reliability.[5, 53, 56, 57] The American College of Obstetricians and Gynecologists´ classification of clinical assessment of fetal station has therefore been questioned due to the inaccuracy of the method.[58] Researchers studying fetal descent have also called for a more objective measure of fetal station than the clinical examination offers.[8, 23] Ultrasound methods also have limitations with inter-observer and inter-device variability,[53, 59] but are more accurate. than clinical examinations. Their use has therefore been encouraged as more objective in recent years.[47, 53, 60] The objective nature of AoP has also been correlated to anatomical landmarks, using MRI and CT techniques.[61, 62]

Visual comparisons show the ultrasound descent pattern to be similar in shape to the clinical curves published by Friedman.[8] The ultrasound assessed fetal head was slightly higher and above the mid-pelvis level initially. In the original clinical data the fetal head was, on average, considered to have advanced below the maternal spinal plane when the active phase had been reached.[8] There are fundamental methodological differences in comparing the clinical assessment of the spinal plane and the results created by using HPD and AoP values to determine fetal head descent but attempts have been made to relate the two.[1, 47, 61-63] Another variation is the relationship between cervical dilatation and rapid descent. The descent started on average at four cm dilatation according to Friedman’s curves and reached its maximum rate of descent at an average of six cm dilatation. We found rapid descent to start around seven to eight cm dilatation but in both cases leading to delivery around four hours later. The duration of the active phase was shorter in Friedman’s curves; 4.9 hours vs. 8.4 hours in our study. This difference may be caused by different definitions of start of active phase of labor. By Friedman´s definition the active phase begins at a variable degree of cervical dilatation but we defined the start of the active phase at four cm in accordance with the actual WHO recommendations. The difference observed may also be caused by changes in the obstetric population or practice. [21-23] Taking into account that the forces which drive the rapid and progressive descent may contrive to build up to a decisive turning point later in the cervical dilatational process of labor. This may be more important than the actual cervical dilatation and calls for more time to be allowed in an otherwise normal labor.

We found that 2nd degree models described the relationship between cervical dilatation and ultrasonically measured fetal head station better than linear models in women delivering vaginally. This differs from the findings of Hamilton et al. who found a linear relationship between cervical dilatation and clinically assessed fetal station.[23]

When the fetal head was in the occiput posterior position at the first measurement, the fetal head station was higher throughout the early part of the active phase. But this did not appear to affect the pattern of rapid descent towards the end of labor, which was similar for all initial occiput positions in women delivering spontaneously.

We defined active labor as regular contractions with a fully effaced and 4 cm dilated cervix, which at the time was the WHO definition of active labor. Since then WHO has changed its definition to a 5 cm dilatation[64] and Zhang et al. recommended 6 cm as the start of the active phase.[17] As we used the time of delivery as the reference point and then calculated backwards, similar to the methodology used by Zhang et al., we do not believe these differences in definition have any bearing on the patterns of descent supported by our findings of almost identical descent patterns for women included at four to five cm dilatation compared with those included with $\geq$ six cm.

In order to get a complete picture of nulliparous women in spontaneous labor we did not exclude women with advanced dilation on admission. This represents the reality of spontaneous labors. Excluding these women would have resulted in a selected population of women having slow labors.

We decided to do paired clinical and ultrasound examinations and follow the hospital protocol for vaginal examinations during labor, i.e. at least every four hours as we felt this would be sufficient to construct labor patterns for the whole group. Having a strict protocol of more frequent examinations would have given us more accurate knowledge of clinical progress for each individual woman.

Studies have shown conflicting results of the effects epidural analgesia has on the progress of labor.[65-79] In our study group 62% of the women had epidural analgesia. There were no differences between the fetal head levels during the early part of the active phase associated with epidural use in women delivering spontaneously, but the curve of fetal head descent was slightly more sloping in these women. This is in line with the results of a recent study using ultrasound methods to monitor fetal head descent.[36] A study following women in induced labors with ultrasound by measuring fetal head descent, has also demonstrated different patterns of labor progress in women delivering vaginally and those needing cesarean delivery.[80]

Oxytocin augmentation was used in 41% of the women and in these labors slower descent was observed. This is not surprising because slow progress is the indication for oxytocin augmentation. Although it would be ideal to study only spontaneous, unstimulated labors, it would be unethical to withhold treatment of labor inertia. The protocol for augmentation used was the agreed protocol at our hospital and the cesarean delivery rate in the study corresponds to the 8% cesarean delivery rate for group 1 in the Robson 10-group classification system at our hospital. We therefore think that the internal validity was good. However, the external validity may be limited by a relatively low overall cesarean delivery rate of 15.3% in Iceland.[81] Similar studies should be performed in other countries and other populations. In our cohort only one cesarean delivery was performed because of fetal distress but this was at full dilatation after slowly progressing dilatation with oxytocin augmentation.

We reported both HPD and AoP measurements because for research purposes these methods are complimentary and reinforce the results when taken together. Although there are methodological differences between the two, with AoP using the symphysis as a reference point and HPD representing the remaining distance for the fetal head to pass to the pelvic outlet, they have been shown to be well correlated.[82] The methods were correlated also in our study and showed similar labor pattern curves suggest these measurements could be used interchangeably. The correlation between ultrasound measurements and clinical assessments in our study was good at high stations, but not at low stations (Supplementary Figure 2).

Strengths and limitations

The strengths of this study were the prospective, longitudinal design and a well-defined population of spontaneously laboring nulliparous women recruited in the active phase of labor. The ultrasound examiners were both fetal medicine specialists, which adds to the quality of the examinations. This could also be considered a weakness as the results might not be directly applicable to the average labor ward staff. It has, however, been shown that these skills are easily obtained.[62, 83] The non-consecutive nature of inclusion may be considered a limitation but inclusions occurred on given days when the ultrasound examiners were available and we are not aware of any selection bias. The small sample size, especially as regards the operative delivery numbers, limits generalizability of the results and further studies in both parous and non-parous women in spontaneous and induced labor are needed.

Conclusions

We used objective, tested, intrapartum ultrasound methods to describe the pattern of fetal head descent in nulliparous women at term. The patterns resemble previously published clinical patterns. Ultrasonically measured fetal head station was associated with mode of delivery and with remaining time in labor. The results of this study may encourage further studies of fetal descent with ultrasound in other well-defined groups of women in labor and in other settings.

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Table 1. Characteristics of the study population

	Cesarean delivery	Instrumental delivery	Spontaneous delivery
	(n=8)	(n=16)	(n=75)
Maternal characteristics			
Maternal age, y	31 (24- 40)	28 (20-38)	26 (18-38)
Body mass index at first visit	26 (23-36)	25 (17-35)	22 (17-36)
Gestational age, wks.	40.5 (37.3-41.6)	40.5 (38-41.7)	39.9 (37-41.9)
Labor characteristics			
Oxytocin augmentation	7 (88)	12 (75)	22 (29)
Epidural analgesia	7 (88)	11 (69)	43 (57)
Length of labor, h	12.8 (8.9-26)	10.2 (4.7-18.9)	7.8 (1.4-24.3)
Newborn characteristics			
Birthweight, g	3790 (3200-4310)	3890 (2750- 4540)	3520 (2480-5000)
Apgar at 1 min	8.5 (5 -10)	8 (2- 9)	9 (2-10)
Apgar at 5 min	10 (9-10)	9 (8-10)	10 (5-10)

Values are median (range) or n (%)

Table 2. Cervical dilatation and ultrasound measurements of fetal head station at first and last examination differentiated into mode of delivery

	Cesarean Delivery (n=8)	Instrumental Delivery (n=16)	Spontaneous Delivery (n=75)	*p* value
At first examination				
Cervical dilation, cm	5 (4-7)	5 (4-8)	5 (4-10)	0.48
Angle of Progression°, (degrees)	88 (73-105)	95 (78-112)	102 (81-128)	0.01
Head-perineum distance, mm	56 (34-66)	47 (35-57)	43 (24-64)	0.02
At last examination				
Cervical dilation, cm	8 (6-10)	10 (5-10)	10 (5-10)	0.01
Angle of Progression°, (degrees)	104 (76-123)	114 (99-155)	123 (82-161)	0.01
Head-perineum distance, mm	47 (33-62)	36 (14-51)	30 (9-57)	0.001

Values are median (range) or n (%)

Table 3. Predicted time to delivery at level of head-perineum distance and angle of progression in women delivering vaginally

Head-perineum distance (mm)	Predicted time to delivery (hours)	95% CI (hours)
60	10.5	9.4-11.6
50	8.0	7.3-8.8
40	5.5	5.1-6.1
30	3.0	2.5-3.8
20	0.6	0.0-1.6
Angle of Progression (°)		
80	9.5	8.7-10.4
95	7.4	6.7-8.0
110	5.2	4.7-5.7
125	3.0	2.4-3.7
140	0.8	0.0-1.8

Figure 1

Title:

Measurement of head-perineum distance (HPD)

Legend:

Transverse transperineal image (frontal plane related to woman) illustrating measurement of head-perineum distance (41 mm in the left image and 21 mm in the right image).

Figure 2

Title:

Measurement of angle of progression (AoP)

Legend:

Sagittal transperineal image illustrating measurement of angle of progression (110 degrees in the left image and 130 degrees in the right image)

Figure 3

Labor curves showing fetal head descent measured with ultrasound and cervical dilatation assessed clinically

Labor curves showing fetal head station measured with ultrasound as head-perineum distance measured in mm (left image) and angle of progression measured in degrees (middle image) and cervical dilatation assessed clinically in cm (right image) against time in nulliparous women with spontaneous onset of labor. Birth is at 0 hours and time from birth was calculated backwards. The 95% confidence intervals are shaded.

Figure 4

Title:

Labor curves showing fetal head descent measured with ultrasound and cervical dilatation assessed clinically stratified by mode of delivery

Legend:

Labor curves showing fetal head station measured with ultrasound as head-perineum distance measured in mm (left image) and angle of progression measured in degrees (middle image) and cervical dilatation assessed clinically in cm (right image) against time in nulliparous women with spontaneous onset of labor, stratified by mode of delivery. Birth is at 0 hours and time from birth was calculated backwards. The 95% confidence intervals are shaded.

Figure 5

Title:

Labor curves showing fetal head descent curves measured with ultrasound stratified by occiput position at inclusion

Legend:

Labor curves showing patterns of fetal head station measured with ultrasound as head-perineum distance measured in mm (left image) and angle of progression measured in degrees (right image) against time in nulliparous women with spontaneous onset of labor at term and also delivering spontaneously, stratified by the fetal occiput position at inclusion. Birth is at 0 hours and time from birth was calculated backwards. The 95% confidence intervals are shaded.

Figure 6

Title:

Labor curves showing fetal head descent curves measured with ultrasound stratified by oxytocin augmentation

Legend:

Labor curves showing patterns of fetal head station measured with ultrasound as head-perineum distance measured in mm (left image) and angle of progression measured in degrees (right image) against time in nulliparous women with spontaneous onset of labor at term and also delivering spontaneously, stratified by oxytocin augmentation during labor. Birth is at 0 hours and time from birth was calculated backwards. The 95% confidence intervals are shaded.

Figure 7

Title:

Labor curves showing fetal head descent curves measured with ultrasound stratified by use of epidural analgesia

Legend:

Labor curves showing patterns of fetal head station measured with ultrasound as head-perineum distance measured in mm (left image) and angle of progression measured in degrees (right image) against time in nulliparous women with spontaneous onset of labor at term and also delivering spontaneously, stratified by the use of epidural analgesia. Birth is at

0 hours and time from birth was calculated backwards. The 95% confidence intervals are shaded.

Figure 8

Title:

Labor curves showing fetal head descent curves measured with ultrasound stratified by cervical dilatation at inclusion

Legend:

Labor curves showing patterns of fetal head station measured with ultrasound as head-perineum distance measured in mm (left image) and angle of progression measured in degrees (right image) against time in nulliparous women with spontaneous onset of labor at term and also delivering spontaneously, stratified by the cervical dilatation at inclusion. Birth is at 0 hours and time from birth was calculated backwards. The 95% confidence intervals are shaded.

Video Clip 1

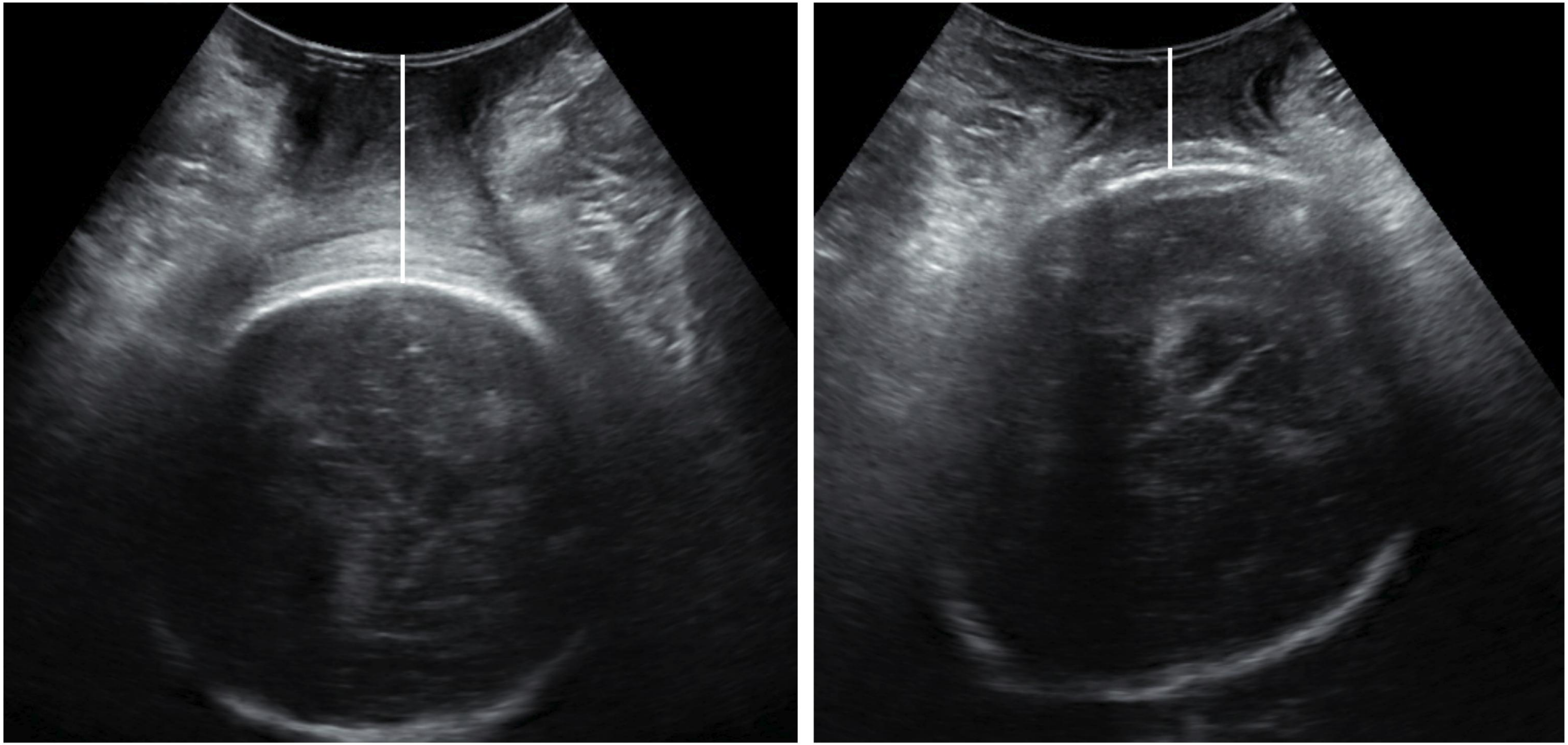
Legend:

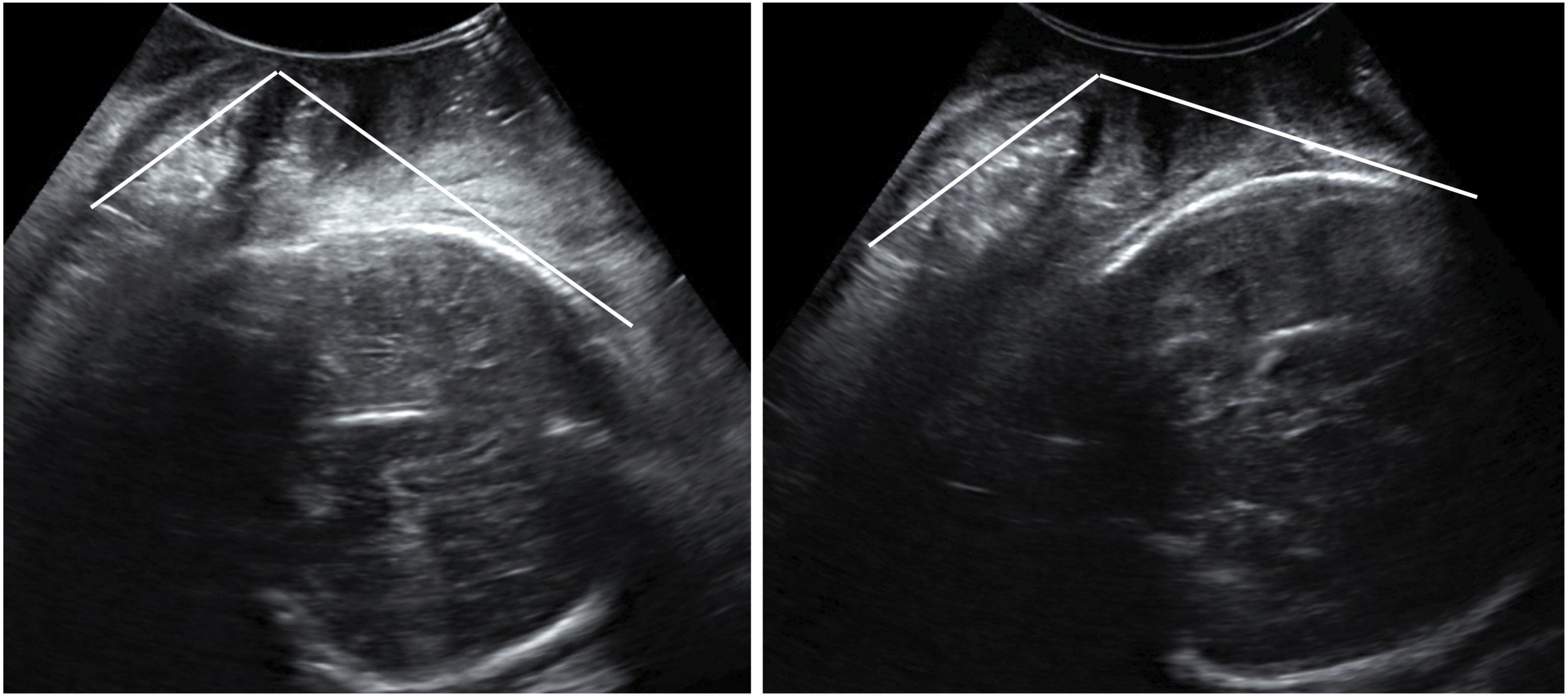
A video clip demonstrating how to obtain the view for measurement of head-perineum distance (HPD)

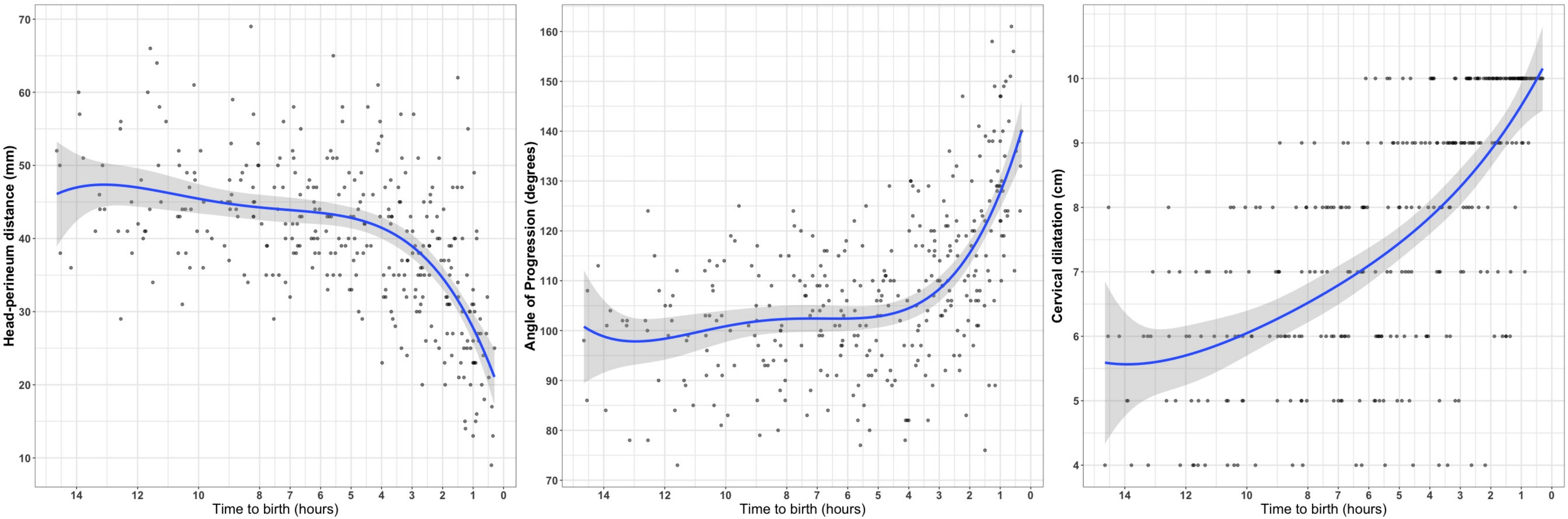
Video Clip 2

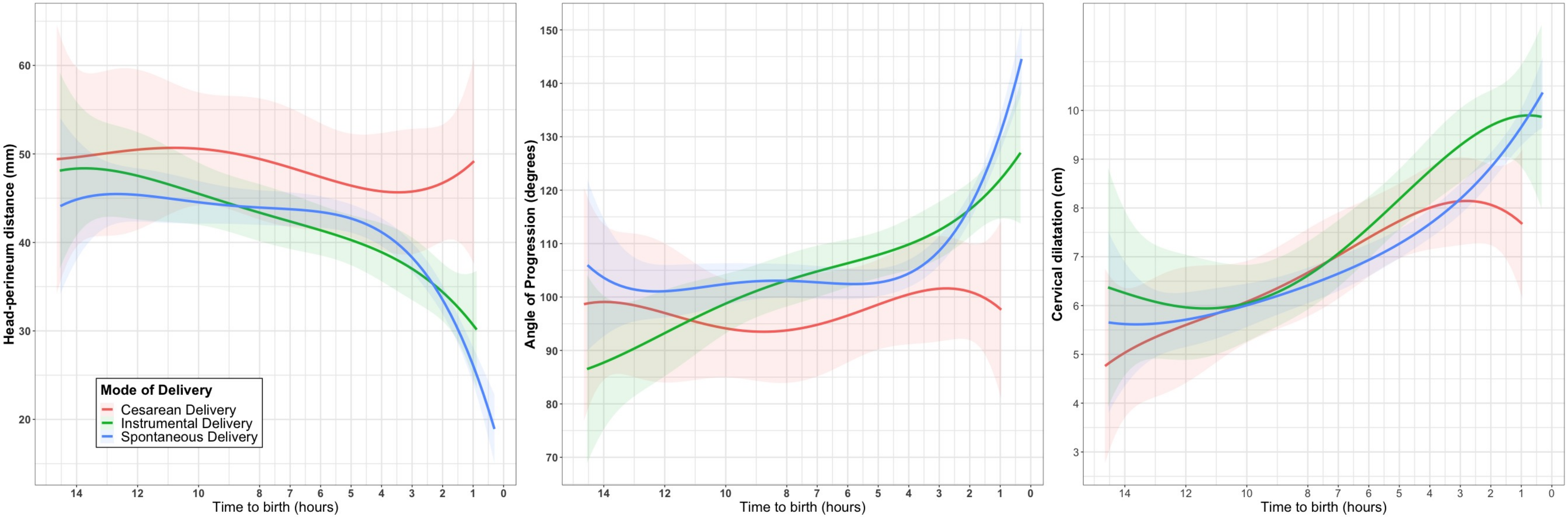
Legend:

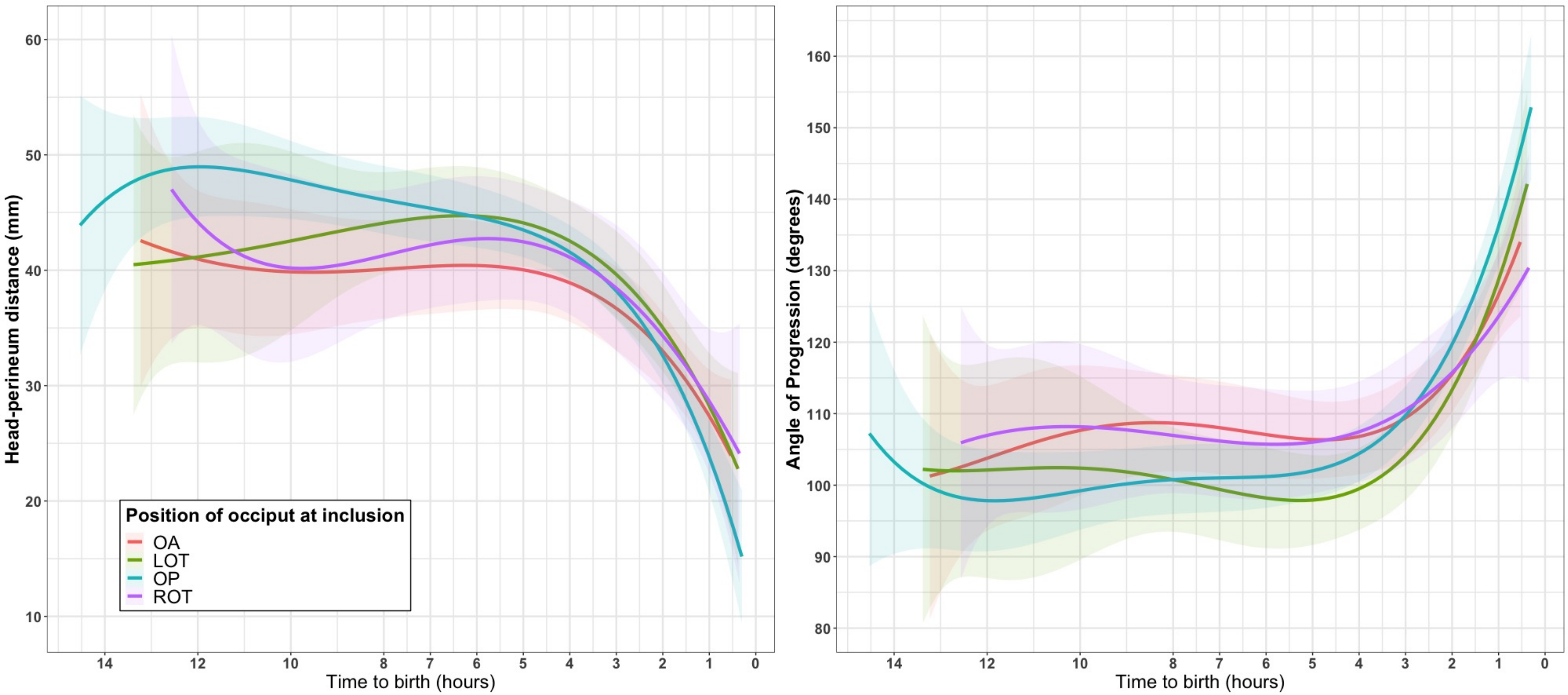
A video clip demonstrating how to obtain the view for measurement of angle of progression (AoP)

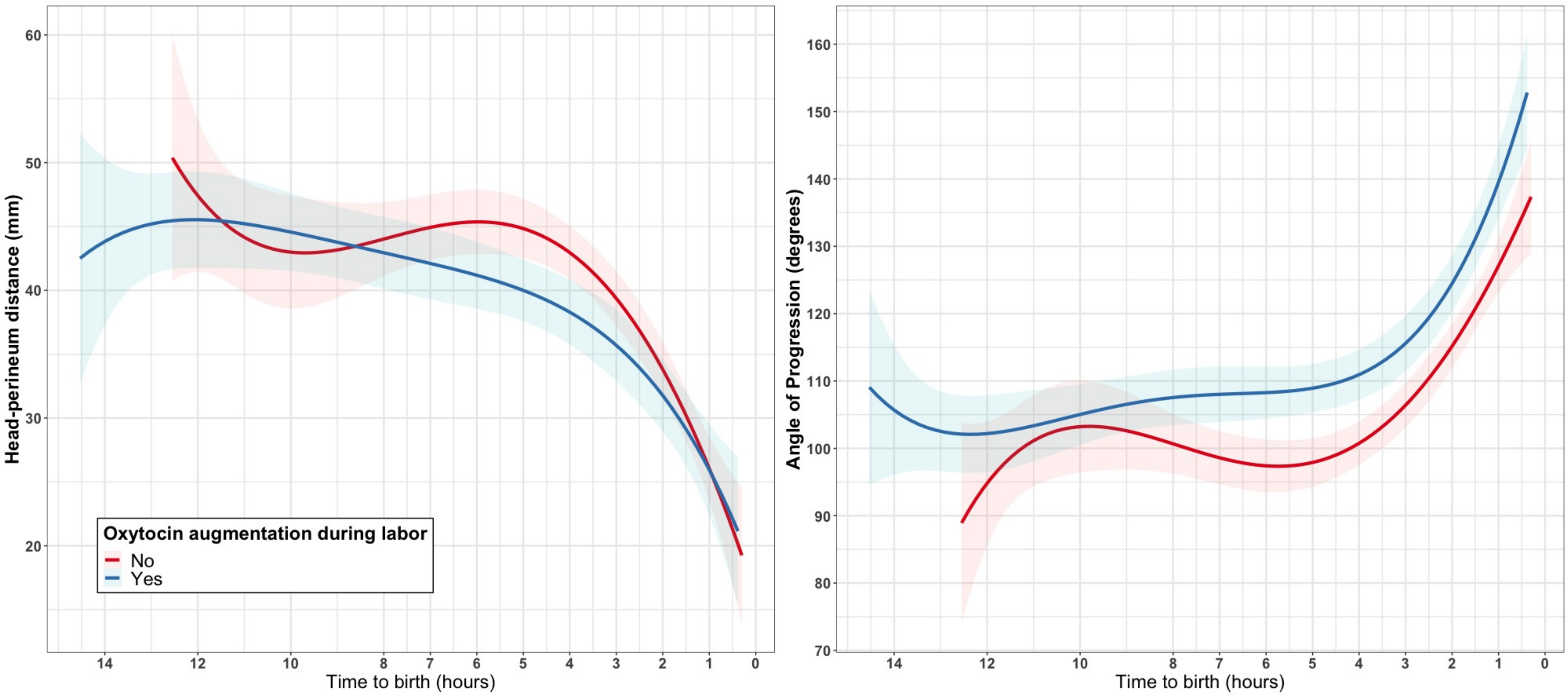




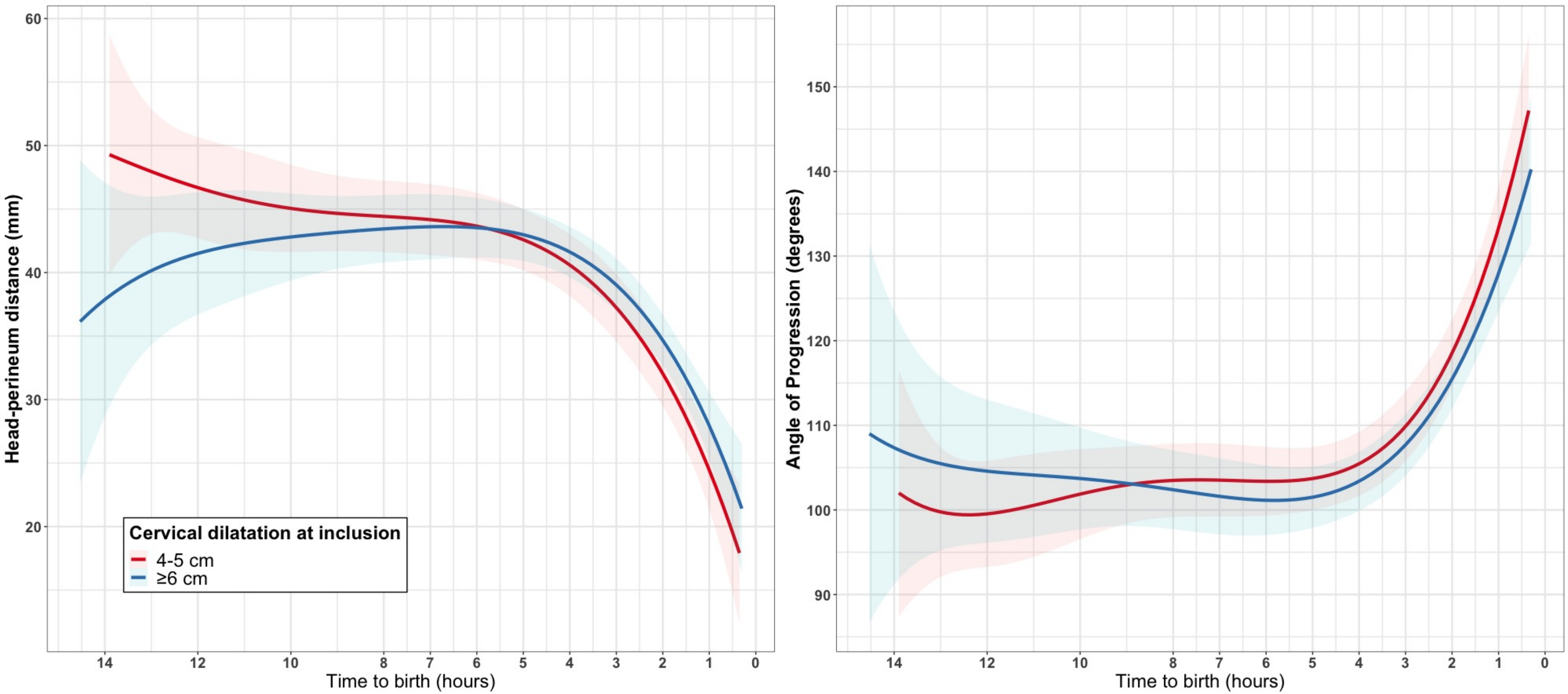

Head-perineum distance (mm)
70
60
50
40
30
20
10
14
12
10
8
7
6
5
4
3
2
1
0
Time to birth (hours)
Angle of Progression (degrees)
160
150
140
130
120
110
100
90
80
70
14
12
10
8
7
6
5
4
3
2
1
0
Time to birth (hours)
Cervical dilatation (cm)
10
9
8
7
6
5
4
14
12
10
8
7
6
5
4
3
2
1
0
Time to birth (hours)


Head-perineum distance (mm)
60
50
40
30
20
Mode of Delivery
Cesarean Delivery
Instrumental Delivery
Spontaneous Delivery
14
12
10
8
7
6
5
4
3
2
1
0
Time to birth (hours)
Angle of Progression (degrees)
150
140
130
120
110
100
90
80
70
Time to birth (hours)
Cervical dilatation (cm)
10
9
8
7
6
5
4
3
Time to birth (hours)

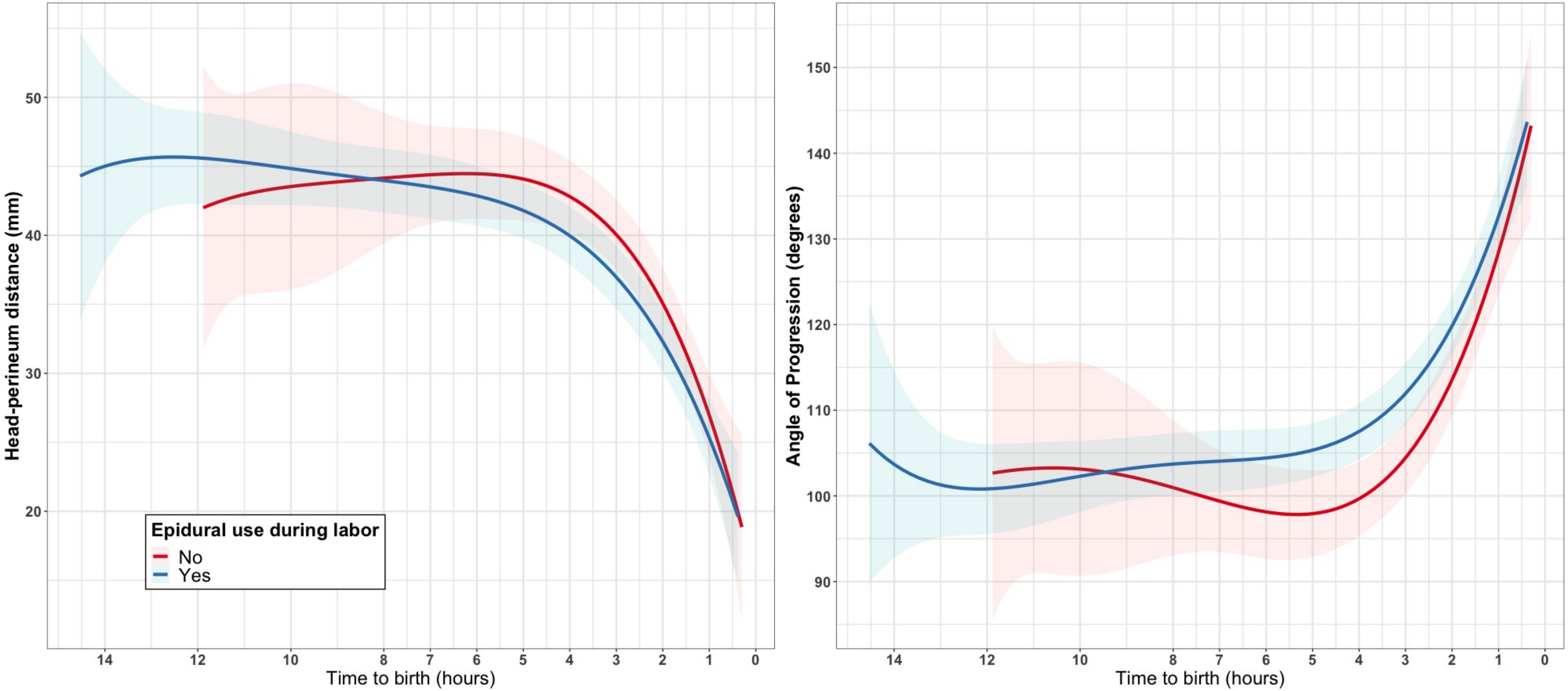

Head-perineum distance (mm)
60
50
40
30
20
10
14
12
10
8
7
6
5
4
3
2
1
0
Time to birth (hours)
Position of occiput at inclusion
OA
LOT
OP
ROT
Angle of Progression (degrees)
160
150
140
130
120
110
100
90
80
14
12
10
8
7
6
5
4
3
2
1
0
Time to birth (hours)



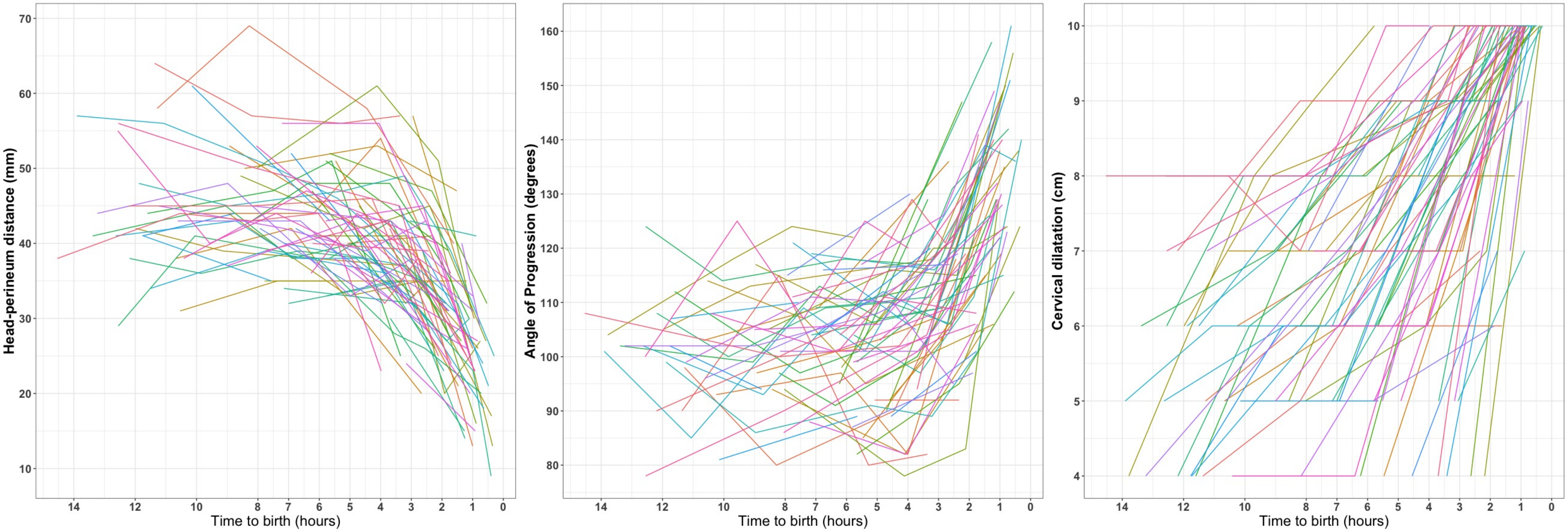
Head-perineum distance (mm)
60
50
40
30
20
14
12
10
8
7
6
5
4
3
2
1
0
Time to birth (hours)
Oxytocin augmentation during labor
No
Yes
Angle of Progression (degrees)
160
150
140
130
120
110
100
90
80
70
14
12
10
8
7
6
5
4
3
2
1
0
Time to birth (hours)

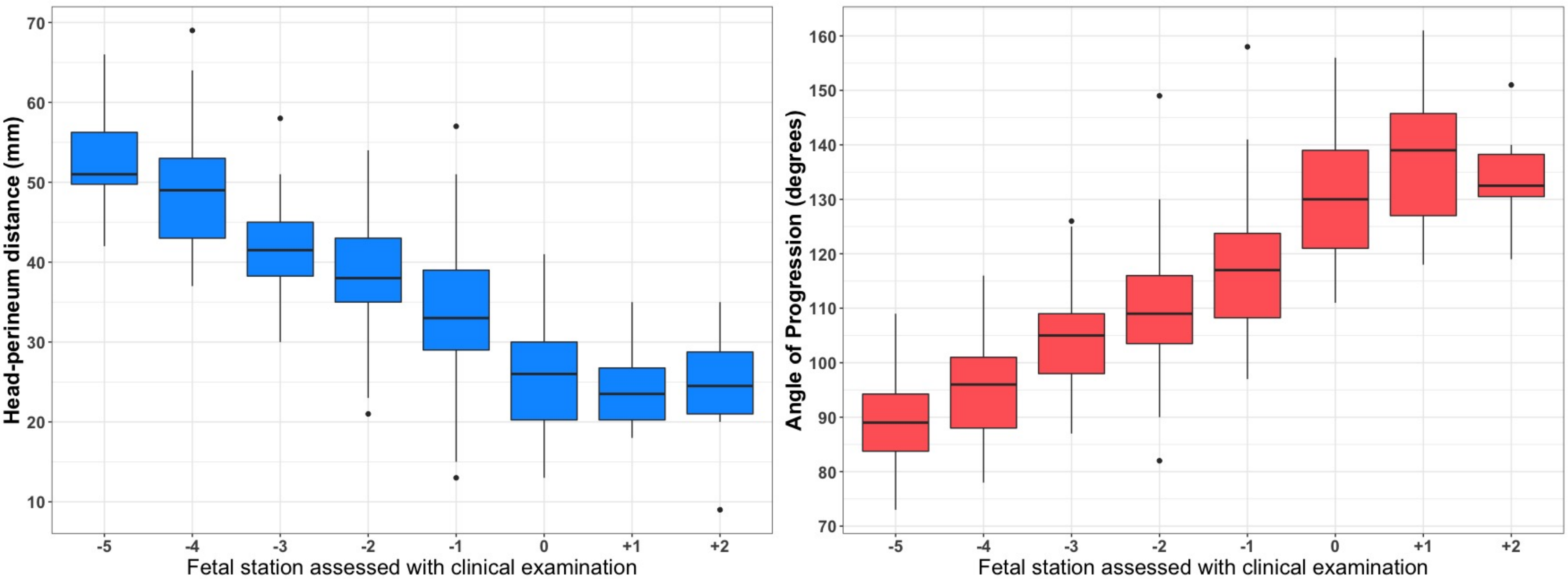


Head-perineum distance (mm)
60
50
40
30
20
14
12
10
8
7
6
5
4
3
2
1
0
Time to birth (hours)
Cervical dilatation at inclusion
4-5 cm
≥6 cm
Angle of Progression (degrees)
150
140
130
120
110
100
90
14
12
10
8
7
6
5
4
3
2
1
0
Time to birth (hours)



Head-perineum distance (mm)
50
40
30
20
Epidural use during labor
No
Yes
14
12
10
8
7
6
5
4
3
2
1
0
Time to birth (hours)
Angle of Progression (degrees)
150
140
130
120
110
100
90
14
12
10
8
7
6
5
4
3
2
1
0
Time to birth (hours)


Head-perineum distance (mm)
Time to birth (hours)
Angle of Progression (degrees)
Time to birth (hours)
Cervical dilatation (cm)
Time to birth (hours)


Head-perineum distance (mm)
70
60
50
40
30
20
10
-5
-4
-3
-2
-1
0
+1
+2
Fetal station assessed with clinical examination
Angle of Progression (degrees)
160
150
140
130
120
110
100
90
80
70
-5
-4
-3
-2
-1
0
+1
+2
Fetal station assessed with clinical examination

Supplementary Table 1. Details of labors for women needing a cesarean delivery

Case	Cervical dilation at inclusion (cm)	Cervical dilatation at delivery (cm)	Occiput position at inclusion	Occiput position at delivery	HPD at inclusion (mm)	HPD at last examination (mm)	AoP at inclusion (°)	AoP at last examination (°)	Length of active phase of labor l (h:m)	Length of 2nd stage (h:m)	Indication
1	4	6	OA	OA	43	34	98	122	17:15		FP
2	5	6	OP	OP	48	47	91	89	10:06		FP
3	6	10	OP	OP	59	49	79	110	08:40	04:53	FP
4	5	8	OP	OP	60	40	84	107	13:55		FP
5	7	9	OP	OP	60	55	84	89	11:35		FP
6	4	10	ROT	OP	52	46	98	100	14:24	00:38	FD
7	5	6	OP	OP	66	62	73	76	11:20		FP
8	4	8	OP	OP	34	33	105	123	25:22		FP

Supplementary Table 2. Predicted ultrasound measured fetal head station at each cm of cervical dilatation

Cervical dilatation (cm)	***Predicted head-perineum distance (mm)***	***95% CI (mm)***	***Predicted angle of progression (°)***	***95% CI (°)***
4	44	42-47	102	98-105
5	46	44-47	99	96-101
6	45	44-47	98	96-100
7	44	42-45	101	98-103
8	40	39-42	106	104-108
9	36	34-37	115	113-117
10	29	28-31	126	124-129

Supplemental Figure 1

Title:

Individual fetal head descent curves measured with ultrasound and cervical dilatation curves assessed clinically

Legend:

Labor curves showing individual patterns of fetal head station measured with ultrasound as head-perineum distance measured in mm (left image) and angle of progression measured in degrees (middle image) and cervical dilatation assessed clinically in cm (right image) against time in nulliparous women with spontaneous onset of labor at term. Only the curves of women delivering spontaneously are shown. Birth is at 0 hours and time from birth was calculated backwards.

Supplemental Figure 2

Title:

The association between clinically assessed station and ultrasound measurements is shown in supplementary figure 2.

Legend:

A boxplot showing the association between clinically assessed fetal station and fetal station measured with ultrasound as head-perineum distance measured in mm (left image) and angle of progression measured in degrees (right image).