Ultrasound Obstet Gynecol 2020; **56**: 597–602
Published online in Wiley Online Library (wileyonlinelibrary.com). **DOI:** 10.1002/uog.21963

New technique for automatic sonographic measurement of change in head–perineum distance and angle of progression during active phase of second stage of labor

L. ANGELI[1], F. CONVERSANO[2], A. DALL'ASTA[1], N. VOLPE[1], M. SIMONE[3], E. DI PASQUO[1], D. PIGNATELLI[2], G. B. L. SCHERA[1], M. DI PAOLA[2], P. RICCIARDI[1], A. FERRETTI[1], T. FRUSCA[1], S. CASCIARO[2] and T. GHI[1]

[1]*Department of Medicine and Surgery, Obstetrics and Gynaecology Unit, University of Parma, Parma, Italy;* [2]*National Research Council, Institute of Clinical Physiology, Lecce, Italy;* [3]*Amolab s.r.l., Lecce, Italy*

KEYWORDS: angle of progression; head–perineum distance; instrumental delivery; intrapartum ultrasound; labor; second stage

CONTRIBUTION

What are the novel findings of this work?
We assessed the performance of a new automatic ultrasound technique for measurement of the change in head–perineum distance and angle of progression, two sonographic parameters that are highly predictive of fetal head station and mode of delivery, during the active phase of the second stage of labor. The algorithm proved to be as accurate as an experienced operator and to quickly provide the necessary measurements.

What are the clinical implications of this work?
The ability to calculate automatically the dynamic change in the most commonly used sonographic indices of fetal head station and progression may provide accurate and fundamental information to the clinician who is managing an obstructed or protracted second stage of labor, avoiding a time-consuming and technically challenging examination.

ABSTRACT

Objective *To evaluate the performance of a new ultrasound technique for the automatic assessment of the change in head–perineum distance (delta-HPD) and angle of progression (delta-AoP) during the active phase of the second stage of labor.*

Methods *This was a prospective observational cohort study including singleton term pregnancies with fetuses in cephalic presentation during the active phase of the second stage of labor. In each patient, two videoclips of 10 s each were acquired transperineally, one in the axial and one in the sagittal plane, between rest and the acme of an expulsive effort, in order to measure HPD and AoP, respectively. The videoclips were processed offline and the difference between the acme of the pushing effort and rest in HPD (delta-HPD) and AoP (delta-AoP) was calculated, first manually by an experienced sonographer and then using a new automatic technique. The reliability of the automatic algorithm was evaluated by comparing the automatic measurements with those obtained manually, which was considered as the reference gold standard.*

Results *Overall, 27 women were included. A significant correlation was observed between the measurements obtained by the automatic and the manual methods for both delta-HPD (intraclass correlation coefficient (ICC) = 0.97) and delta-AoP (ICC = 0.99). The high accuracy provided by the automatic algorithm was confirmed by the high values of the coefficient of determination (r^2 = 0.98 for both delta-HPD and delta-AoP) and the low residual errors (root mean square error = 1.2 mm for delta-HPD and 1.5° for delta-AoP). A Bland–Altman analysis showed a mean difference of 0.52 mm (limits of agreement, −1.58 to 2.62 mm) for delta-HPD (P = 0.034) and 0.35° (limits of agreement, −2.54 to 3.09°) for delta-AoP (P = 0.39) between the manual and automatic measurements.*

Conclusions *The automatic assessment of delta-AoP and delta-HPD during maternal pushing efforts is feasible. The automatic measurement of delta-AoP appears to be reliable when compared with the gold standard manual measurement by an experienced operator. Copyright © 2020 ISUOG. Published by John Wiley & Sons Ltd.*

Correspondence to: Prof. T. Ghi, Department of Medicine and Surgery, Obstetrics and Gynaecology Unit, University of Parma, Viale A. Gramsci 14, 43126 Parma, Italy (e-mail: tullioghi@yahoo.com)

Accepted: 29 December 2019

 ORIGINAL PAPER

INTRODUCTION

The progression of the fetal head in the birth canal under the force of maternal pushing efforts together with uterine contractions is often used as a variable to predict labor outcome[1]. During this active phase, digital examination of the fetal head is known to have limited accuracy in determining the level of the fetal skull and its descent along the birth canal[2,3].

Transperineal ultrasound has been recently endorsed as a complementary tool for the management of prolonged second stage of labor[4–8]. Using this approach, several sonographic parameters have been shown to be more accurate and reproducible than digital examination in defining the fetal head station[9–15]. Among these, the International Society of Ultrasound in Obstetrics and Gynecology (ISUOG) guidelines recommend measurement of the head–perineum distance (HPD) and angle of progression (AoP) for the assessment of fetal head station[16].

Rather than the absolute value obtained at rest, the dynamic change in these parameters during maternal pushing has been shown to be helpful in assessing the progression of the head during the second stage of labor and in anticipating the outcome of instrumental vaginal delivery[17–20]. Furthermore, evaluation of the dynamic change in AoP has been proven to be useful in sonographically coached pushing during the active second stage of labor, as a quantitative measure of the effectiveness of maternal pushing efforts[21,22].

The change in AoP and HPD during maternal pushing is not assessed routinely. In fact, the superiority of assessing the change in these parameters compared with the static assessment has not been demonstrated. Furthermore, evaluation of such dynamic changes may be time-consuming in a context in which rapid decision-making is required in order to achieve prompt and appropriate intervention.

The aim of this study was to assess the performance of a new algorithm for the automatic measurement of the change in AoP and HPD during the active phase of the second stage of labor, and to evaluate its reliability in comparison with the gold standard manual measurement by an experienced operator.

METHODS

This was a prospective cohort study conducted at the University Hospital of Parma between May 2018 and January 2019. A non-consecutive series of uncomplicated singleton term (> 37 weeks of gestation) pregnancies in active labor, with fetuses in cephalic presentation, were considered eligible for the study. The study protocol was approved by the local ethics committee of the University Hospital of Parma (270/2018/OSS/AOUPR), and signed informed consent was obtained from all patients prior to enrolment.

All patients underwent conventional labor management and those who consented to study enrolment underwent transperineal ultrasound during the active phase of the second stage of labor. The ultrasound examination was performed by one of the project investigators (T.G., A.D., L.A. or N.V.), who was blinded to the clinical findings and not involved in the clinical management of the patient but was available upon request for research purposes.

All ultrasound examinations were performed using the SensUS Touch system (Amolab Srl, Lecce, Italy; www.amolab.it), a portable ultrasound device consisting of a tablet personal computer equipped with a 3.5-MHz convex transducer. In each patient, two videoclips were acquired transperineally, one in the axial and one in the sagittal plane, with the woman in a semi-recumbent position and with empty bladder. Each videoclip acquisition encompassed one single pushing effort. The two videoclips in each patient were acquired on two consecutive contractions. The duration of the videoclip was set at 10 s with a frame rate of 8/s (i.e. 80 frames per clip).

In each videoclip obtained, measurement of the HPD and the AoP was carried out offline in the axial and in the sagittal planes, respectively, by one of the project investigators (A.D.). Both parameters were first measured manually on the frame sequence, in the first instance at rest, prior to maternal efforts and/or uterine contractions, and then at the acme of the pushing effort. The change in HPD and AoP between the acme of the pushing effort and rest was defined as delta-HPD and delta-AoP, respectively. These were calculated by A.D. who analyzed all frames in each videoclip and selected for measurement the ultrasound image corresponding to the 'rest' condition and that corresponding to the maximum pushing effort, in order to obtain the largest change in the two parameters.

Following the manual calculation, measurement of delta-HPD and delta-AoP was carried out automatically on each videoclip by the algorithm described below.

The automatic algorithm developed for this study was based on a previously validated approach for the automatic assessment of AoP[23,24] and of HPD[25] at rest, which uses morphological filters and pattern recognition methods to identify the reference landmarks (i.e. the pubic symphysis, the fetal head and the perineal interface) and their geometric features on grayscale ultrasound. The approach for automatic segmentation was applied only to the first image frame of the sequence and included the following steps: (1) conversion of the image into a binary map (i.e. black-and-white image); (2) selection of the anatomical landmarks based on their position and geometry and on the use of dedicated filters; (3) a final 'quality check' based on global geometric considerations that include the orientation of the longitudinal axis of the pubic symphysis and the shape of the fetal head. The pixel patterns corresponding to the landmark structures identified in the first image frame of the sequence were used as the reference for the pattern-tracking algorithm, which was used to identify the landmark structures in the subsequent images. This included the following steps: (1) selection of the 'candidate' structure potentially representing the target anatomical landmark by evaluating all the clusters of bright pixels within a fixed image where the anatomical structure is expected to be; (2) extraction of specific texture features from each candidate, in order to characterize each of them; (3) identification of the actual anatomical landmark, which represents the candidate with a set of features that have minimal difference with respect to the set of reference features extracted from the structure segmented automatically in the first image.

When the analysis of the 80 frames of the sequence was completed, then the algorithm evaluated the relative position of the identified landmark structures (i.e. the pubic symphysis and fetal head for the AoP, and the fetal head and perineal interface for the HPD) and calculated the AoP or the HPD in each frame. The automatic calculation of delta-HPD and delta-AoP represented the difference between the minimum value measured at rest and the maximum value measured at the acme of the pushing effort (Videoclips S1 and S2).

When the measurement was obtained, in order to ensure optimal accuracy, the operator was asked whether the measurement was technically correct or whether another acquisition needed to be performed. The algorithm may require serial videoclip acquisitions in order to obtain optimal views for the automated measurement of delta-HPD and delta-AoP.

Data analysis was performed on a laptop equipped with an Intel i7 Core™ i7-3610QM processor at 2.3 GHz (8 GB of RAM, 64 bits). The automatic software took a total of 30 s to process an entire sequence of images and provide the results.

The normality of the distribution of continuous variables was preliminarily evaluated by means of the Kolmogorov–Smirnov and the Shapiro–Wilk tests and data were presented as mean ± SD or as median (range) accordingly. The accuracy of the automatic algorithm was assessed by comparing the automatic values of delta-HPD and delta-AoP with those resulting from manual segmentation performed by an experienced operator (used as the reference). For both considered parameters, the correlation between manual and automatic measurements was assessed through calculation of the intraclass correlation coefficient (ICC), the coefficient of determination (r^2) and the root mean square error (RMSE). The significance level of systematic differences was assessed using a one-sample Student's *t*-test. Furthermore, agreement between the automatic and manual methods was evaluated as recommended by Bland and Altman, by calculating the paired difference for each measurement and estimating the bias and 95% limits of agreement (LOA) relative to the average measurement of both methods.

RESULTS

Overall, 27 women were included in the study analysis. In each patient, delta-HPD and delta-AoP were calculated using both the manual and the automatic methods. The characteristics of the study population are shown in Table 1. The results of the automatic calculation were obtained in 30 s for each acquired videoclip.

Table 1 Characteristics of 27 uncomplicated singleton term pregnancies included in study

Parameter	*Value*
Maternal age (years)	33.1 ± 4.3
Maternal BMI (kg/m^2)	24.9 ± 5
Parous	2 (7.4)
Gestational age (weeks)	39 + 1 ± 1.37
Occiput position at time of ultrasound acquisition	
Occiput anterior	24 (88.9)
Occiput posterior	2 (7.4)
Occiput transverse	1 (3.7)
Mode of delivery	
Vaginal	18 (66.7)
Cesarean section	7 (25.9)
Instrumental	2 (7.4)
Birth weight (kg)	3.3 ± 0.4

Data are given as mean ± SD or *n* (%). BMI, body mass index.

A significant correlation was observed between the measurements obtained automatically by the algorithm and those obtained by the expert manual segmentation for both delta-HPD (ICC = 0.97) and delta-AoP (ICC = 0.99) (Table 2). The high accuracy provided by the automatic method was confirmed by the high values of the coefficient of determination ($r^2 = 0.98$ for delta-HPD and 0.98 for delta-AoP) and the low residual errors (RMSE = 1.2 mm for delta-HPD and 1.5° for delta-AoP). The Bland–Altman analysis demonstrated an overall mean difference in delta-HPD of 0.52 (LOA, −1.58 to 2.62) mm and in delta-AoP of 0.35 (LOA, −2.54 to 3.09)° (Figure 1).

Analysis of the systematic difference between the manual and automatic measurements showed no significant difference for delta-AoP ($P = 0.39$) whereas the automatic measurement of delta-HPD resulted in a value of about 0.5 mm higher than the corresponding manual measurement ($P = 0.034$) (Table 2). No case of negative values of the delta-HPD or of the delta-AoP was recorded.

DISCUSSION

The automatic calculation of delta-HPD and delta-AoP during the second stage of labor is feasible and provides reliable measurements of delta-AoP as compared with the gold standard manual measurement. The automatic measurement of delta-HPD yielded higher values compared with those estimated manually by experienced operators, but this difference was deemed to be not relevant clinically.

Assessment of progression of the fetal head in the birth canal during pushing efforts may be performed when labor obstruction is suspected[1] or to evaluate the feasibility of instrumental vaginal delivery[26,27]. Assessment of fetal head descent is classically based on digital palpation of the fetal head during maternal pushing. However, it has been demonstrated that the accuracy of digital examination is suboptimal[2,3], particularly in the presence of caput

Table 2 Intraclass correlation coefficient (ICC) and difference between manual and automatic measurements of change in head–perineum distance (delta-HPD) and change in angle of progression (delta-AoP) between rest and acme of pushing effort during active phase of second stage of labor ($n = 27$)

		Difference between automatic and manual measurements				
	ICC	*Mean (95% CI)*	*Lower limit (95% CI)*	*Upper limit (95% CI)*	*Range*	P*
Delta-HPD (mm)	0.97	0.52 (0.04 to 0.99)	−1.58 (−2.40 to −0.75)	2.62 (1.79 to 3.44)	−1.78 to 2.41	0.034
Delta-AoP (°)	0.99	0.35 (−0.37 to 0.93)	−2.54 (−3.67 to −1.4)	3.09 (1.95 to 4.23)	−2.6 to 2.56	0.39

*Systematic difference between automatic and manual methods was assessed by means of one-sample *t*-test.

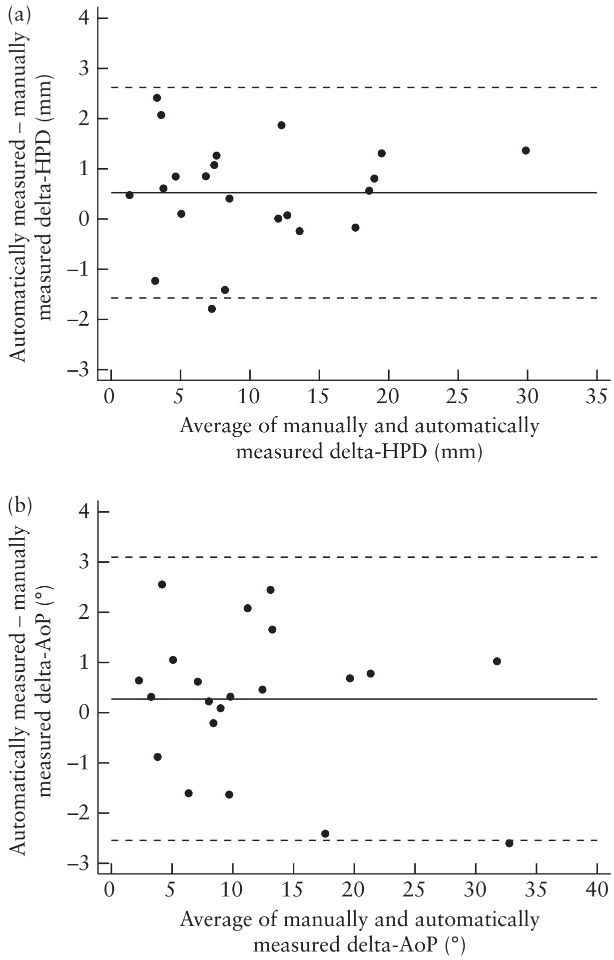

Figure 1 Bland–Altman plots for comparison of automatic and manual measurements of change in head–perineum distance (delta-HPD) (a) and change in angle of progression (delta-AoP) (b) between rest and acme of pushing effort during active phase of second stage of labor. Mean and 95% limits of agreement are shown.

and cranial moulding. In the past decade, transperineal ultrasound has proven to be reproducible and accurate in assessing the fetal head station[9–12,28–30].

Among the different ultrasound parameters that have been proposed for the evaluation of fetal head progression and prediction of delivery outcome, the AoP and HPD have gained popularity and are increasingly used in the management of abnormal labor progression[4–8,17–20,31–36]. On this basis, the recent ISUOG guideline has recommended their routine measurement in pregnancies with prolonged second stage of labor or before considering operative delivery[16].

In the majority of the studies conducted so far, the correlation between transperineal ultrasound findings and the outcome of second stage of labor has been based on the values measured at rest. On the other hand, the sonographic assessment of the progression of the fetal skull through the birth canal during maternal pushing has been proposed as an additional method to predict labor obstruction[17–20,29].

A narrow AoP at the acme of the pushing effort has been found to be predictive of complicated instrumental delivery[17,20,33] whereas Lau *et al.* reported that a change in the AoP > 15° predicted 73% of successful vaginal extractions in their cohort[18]. In a recent multicenter prospective study of women with prolonged second stage of labor, delta-HPD was found to be inversely related to the duration of operative vaginal delivery, the risk of failure and the need of a subsequent Cesarean delivery[19].

On these grounds, despite the paucity of data, a dynamic rather than a static transperineal ultrasound assessment seems more appropriate in the prediction of labor outcome. However, the changes in ultrasound parameters during contractions are not quantified routinely in clinical practice. This may be due to the fact that online, fast and accurate calculation of delta-AoP and/or delta-HPD during the pushing effort seems to be technically demanding even for experienced operators.

New automatic approaches have been recently developed for the measurement of the main transperineal ultrasound parameters. Previous studies have validated the accuracy of these approaches in measuring the HPD[25] and the AoP at rest[23,24]. Conversano *et al.*[23] proposed an algorithm that can calculate the AoP based on a pattern recognition method that identifies the pubic symphysis and the fetal head. Youssef *et al.*[24] reported a different method for the automatic measurement of the AoP that was based on commercially available software; however software technical features were not detailed, thus limiting the comparability of the two methods.

The present study has provided original data on the feasibility of the automatic assessment of HPD and AoP changes during a contraction. The algorithm described herein is able to quantify within a few seconds the relative change in these parameters during maternal pushing, thereby measuring the values of delta-AoP and delta-HPD in a given contraction. In our small cohort, the algorithm yielded accurate measurements of the delta-AoP, which were comparable to those obtained manually by an experienced operator. On the other hand, the automatic method was associated with a slight overestimation, of less than 1 mm, of delta-HPD compared with the measurements obtained manually. However, we consider that this small difference is of no relevance when considered in the clinical context.

The number of acquisitions performed in the present study was not recorded, but it should be acknowledged that serial attempts may be required in order to obtain optimal views for the automated measurement of delta-HPD and delta-AoP.

The strengths of the present study are its prospective design and the reliability of the manual analysis of the images, which was always performed by a sonographer with expertise in the field of intrapartum ultrasound.

The limitations of the study are mainly related to the small number of included cases. Therefore, even though our results are encouraging, it is premature to declare that the automatic method actually works. Furthermore, the relationship between the quantitative changes of the two parameters during maternal pushing is of interest but has not been intentionally investigated. As AoP and HPD are measured on different planes, they have not been acquired during the same contraction but on two consecutive ones, which may affect the extent of their correlation.

In our series no case of negative delta-HPD was obtained. This is in contrast to a recent large multicenter study in which a few cases of negative change in the HPD during maternal pushing were observed[19]. The authors proposed that this may be due to inappropriate coactivation of the levator ani muscle during the pushing effort. Some authors previously reported that the inappropriate activation of the levator ani is common at term gestation[37], and thus we speculate that this may occur also during the second stage of labor.

In this study, we decided to test only the feasibility and the accuracy of the automatic calculation of delta-AoP and delta-HPD and we did not assess the dynamic change in these parameters according to fetal occiput position, head station or other factors that are known to affect the extent of the fetal skull descent during pushing, such as parity, epidural, augmentation, birth weight, interval between beginning of the second stage and ultrasound[23–25].

In conclusion, automatic assessment of the change in HPD and AoP during the maternal pushing efforts in the second stage of labor is feasible and reliable. Further studies are required in order to confirm the accuracy of this automatic tool and to demonstrate its clinical advantages in a routine setting.

REFERENCES

1. Normal labor and delivery. In: *Williams Obstetrics* (22nd edn), Cunningham FG, Leveno KJ, Bloom SL, Hauth JC, Gilstrap LC III, Wenstrom KD (eds). McGraw-Hill: New York, NY, 2005, 409–441.
2. Buchmann E, Libhaber E. Interobserver agreement in intrapartum estimation of fetal head station. *Int J Gynaecol Obstet* 2008; **101**: 285–289.
3. Dupuis O, Silveira R, Zentner A, Dittmar A, Gaucherand P, Cucherat M, Redarce T, Rudigoz RC. Birth simulator: reliability of transvaginal assessment of fetal head station as defined by the American College of Obstetricians and Gynecologists classification. *Am J Obstet Gynecol* 2005; **192**: 868–874.
4. Kalache KD, Dückelmann A, Michaelis S, Lange J, Cichon G, Dudenhausen J. Transperineal ultrasound imaging in prolonged second stage of labor with occipitoanterior presenting fetuses: how well does the 'angle of progression' predict the mode of delivery? *Ultrasound Obstet Gynecol* 2009; **33**: 326–330.
5. Gilboa Y, Kivilevitch Z, Spira M, Kedem A, Katorza E, Moran O, Achiron R. Head progression distance in prolonged second stage of labor: relationship with mode of delivery and fetal head station. *Ultrasound Obstet Gynecol* 2013; **41**: 436–441.
6. Masturzo B, De Ruvo D, Gaglioti P, Todros T. Ultrasound imaging in prolonged second stage of labor: does it reduce the operative delivery rate? *J Matern Fetal Neonatal Med* 2014; **27**: 1560–1563.
7. Dall'Asta A, Angeli L, Masturzo B, Volpe N, Luca Schera GB, Di Pasquo E, Girlando F, Attini R, Menato G, Frusca T, Ghi T. Prediction of spontaneous vaginal delivery in nulliparous women with a prolonged second stage of labor: the value of intrapartum ultrasound. *Am J Obstet Gynecol* 2019; **221**: 642.e1–13.
8. Chan VYT, Lau WL, So MKP, Leung WC. Measuring angle of progression by transperineal ultrasonography to predict successful instrumental and caesarean deliveries during prolonged second stage of labor. *Int J Gynaecol Obstet* 2019; **144**: 192–198.
9. Maticot-Baptista D, Ramanah R, Collin A, Martin A, Maillet R, Riethmuller D. Ultrasound in the diagnosis of fetal head engagement. A preliminary French prospective study. *J Gynecol Obstet Biolog Reprod* 2009; **38**: 474–480.
10. Chan YT, Ng VK, Yung WK, Lo TK, Leung WC, Lau WL. Relationship between intrapartum transperineal ultrasound measurement of angle of progression and head-perineum distance with correlation to conventional clinical parameters of labor progress and time to delivery. *J Matern Fetal Neonatal Med* 2015; **28**: 1476–1481.
11. Hassan WA, Eggebo T, Ferguson M, Gillett A, Studd J, Pasupathy D, Lees CC. The sonopartogram: a novel method for recording progress of labor by ultrasound. *Ultrasound Obstet Gynecol* 2014; **43**: 189–194.
12. Tutschek B, Torkildsen EA, Eggebø TM. Comparison between ultrasound parameters and clinical examination to assess fetal head station in labor. *Ultrasound Obstet Gynecol* 2013; **41**: 425–429.
13. Tutschek B, Braun T, Chantraine F, Henrich W. A study of progress of labour using intrapartum translabial ultrasound, assessing head station, direction, and angle of descent. *BJOG* 2011; **118**: 62–69.
14. Eggebø T, Gjessing L, Heien C, Smedvig E, Økland I, Romundstad P, Salvesen KA. Prediction of labor and delivery by transperineal ultrasound in pregnancies with prelabor rupture of membranes at term. *Ultrasound Obstet Gynecol* 2006; **27**: 387–391.
15. Barbera A, Pombar X, Perugino G, Lezotte D, Hobbins J. A new method to assess fetal head descent in labor with transperineal ultrasound. *Ultrasound Obstet Gynecol* 2009; **33**: 313–319.
16. Ghi T, Eggebø T, Lees C, Kalache K, Rozenberg P, Youssef A, Salomon LJ, Tutschek B. ISUOG Practice Guidelines: intrapartum ultrasound. *Ultrasound Obstet Gynecol* 2018; **52**: 128–139.
17. Cuerva MJ, Bamberg C, Tobias P, Gil MM, De La Calle M, Bartha JL. Use of intrapartum ultrasound in the prediction of complicated operative forceps delivery of fetuses in non-occiput posterior position. *Ultrasound Obstet Gynecol* 2014; **43**: 687–692.
18. Lau WL, Leung WC, Chin R. What is the best transperineal ultrasound parameter for predicting success of vacuum extraction? *Ultrasound Obstet Gynecol* 2009; **33**: 735; author reply 736.
19. Kahrs BH, Usman S, Ghi T, Youssef A, Torkildsen EA, Lindtjørn E, Østborg TB, Benediktsdottir S, Brooks L, Harmsen L, Salvesen KÅ, Lees CC, Eggebø TM. Descent of fetal head during active pushing: a secondary analysis of a prospective cohort study investigating ultrasound examinations before an operative vaginal delivery. *Ultrasound Obstet Gynecol* 2019; **54**: 524–529.
20. Antonio Sainz J, Borrero C, Aquise A, García-Mejido JA, Gutierrez L, Fernández-Palacín A. Intrapartum translabial ultrasound with pushing used to predict the difficulty in vacuum-assisted delivery of fetuses in non-occiput posterior position. *J Matern Fetal Neonatal Med* 2016; **29**: 3400–3405.
21. Gilboa Y, Frenkel TI, Schlesinger Y, Rousseau S, Hamiel D, Achiron R, Perlman S. Visual biofeedback using transperineal ultrasound in second stage of labor. *Ultrasound Obstet Gynecol* 2018; **52**: 91–96.
22. Bellussi F, Alcamisi L, Guizzardi G, Parma D, Pilu G. Traditionally *vs* sonographically coached pushing in second stage of labor: a pilot randomized controlled trial. *Ultrasound Obstet Gynecol* 2018; **52**: 87–90.
23. Conversano F, Peccarisi M, Pisani P, Di Paola M, De Marco T, Franchini R, Greco A, D'Ambrogio G, Casciaro S. Automatic ultrasound technique to measure angle of progression during labor. *Ultrasound Obstet Gynecol* 2017; **50**: 766–775.
24. Youssef A, Salsi G, Montaguti E, Bellussi F, Pacella G, Azzarone C, Farina A, Rizzo N, Pilu G. Automated measurement of the angle of progression in labor: a feasibility and reliability study. *Fetal Diagn Ther* 2017; **41**: 293–299.
25. Dall'Asta A, Conversano F, Simone M, Volpe N, Di Paola M, Schera GB, Ferretti A, Ricciardi P, Casciaro S, Frusca T, Ghi T. EP23.01: Development of a new software for the automatic and non-invasive evaluation of labour progression parameters during contractions. *Ultrasound Obstet Gynecol* 2019; **54**(S1): 384–385.
26. American College of Obstetrics and Gynecologist. Operative vaginal delivery. Clinical management guidelines for obstetrician-gynecologists. *Int J Gynaecol Obstet* 2001; **74**: 69–76.
27. Royal College of Obstetricians and Gynaecologists (RCOG). Operative vaginal delivery. Green-top guideline no **26**. RCOG: London, 2011. https://www.rcog.org .uk/globalassets/documents/guidelines/gtg_26.pdf
28. Benediktsdottir S, Salvesen KA, Hjartardottir H, Eggebo TM. Reproducibility and acceptability of ultrasound measurements of head-perineum distance. *Acta Obstet Gynecol Scand* 2018; **97**: 97–103.
29. Sainz JA, Fernandéz-Palacìn A, Borrero C, Aquise A, Ramos Z, Garcìa-mejido JA. Intra and interobserver variability of intrapartum transperineal ultrasound measurements with contraction and pushing. *J Obstet Gynaecol* 2018; **38**: 333–338.

30. Ghi T, Farina A, Pedrazzi A, Rizzo N, Pelusi G, Pilu G. Diagnosis of station and rotation of the fetal head in the second stage of labor with intrapartum translabial ultrasound. *Ultrasound Obstet Gynecol* 2009; **33**: 331–336.
31. Ghi T, Maroni E, Youssef A, Morselli-Labate AM, Paccapelo A, Montaguti E, Rizzo N, Pilu G. Sonographic pattern of fetal head descent: relationship with duration of active second stage of labor and occiput position at delivery. *Ultrasound Obstet Gynecol* 2014; **44**: 82–89.
32. Bultez T, Quibel T, Bouhanna P, Popowski T, Resche-Rigon M, Rozenberg P. Angle of fetal head progression measured using transperineal ultrasound as a predictive factor of vacuum extraction failure. *Ultrasound Obstet Gynecol* 2016; **48**: 86–91.
33. Sainz JA, García-Mejido JA, Aquise A, Bonomi MJ, Borrero C, De La Fuente P, Fernández-Palacín A. Intrapartum transperineal ultrasound used to predict cases of complicated operative (vacuum and forceps) deliveries in nulliparous women. *Acta Obstet Gynecol Scand* 2017; **96**: 1490–1497.
34. Sainz JA, García-Mejido JA, Aquise A, Borrero C, Bonomi MJ, Fernández-Palacín A. A simple model to predict the complicated operative vaginal deliveries using vacuum or forceps. *Am J Obstet Gynecol* 2019; **220**: 193.e1–12.
35. Carvalho Neto RH, Viana Junior AB, Moron AF, Araujo Júnior E, Carvalho FHC, Feitosa HN. Assessment of the angle of progression and distance perineum-head in the prediction of type of delivery and duration of labor using intrapartum ultrasonography. *J Matern Fetal Neonatal Med* 2019; 18: 1–9.
36. Kasbaoui S, Séverac F, Aïssi G, Gaudineau A, Lecointre L, Akladios C, Favre R, Langer B, Sananès N. Predicting the difficulty of operative vaginal delivery by ultrasound measurement of fetal head station. *Am J Obstet Gynecol* 2017; **216**: 507.e1–9.
37. Kamel R, Montaguti E, Nicolaides KH, Soliman M, Dodaro MG, Negm S, Pilu G, Momtaz M, Youssef A. Contraction of the levator ani muscle during Valsalva maneuver (coactivation) is associated with a longer active second stage of labor in nulliparous women undergoing induction of labor. *Am J Obstet Gynecol* 2019; **220**: 189.e1–8.

SUPPORTING INFORMATION ON THE INTERNET

The following supporting information may be found in the online version of this article:

Videoclip S1 Automatic calculation of difference between head–perineum distance (HPD) measured at acme of maternal pushing and HPD measured at rest (delta-HPD).

Videoclip S2 Automatic calculation of difference between angle of progression (AoP) measured at acme of maternal pushing and AoP measured at rest (delta-AoP).

