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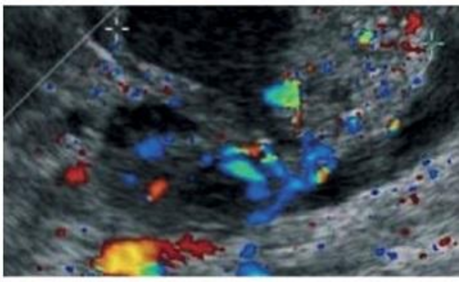

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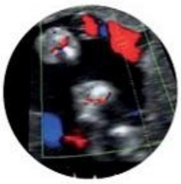

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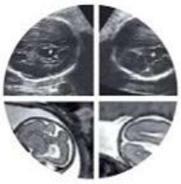

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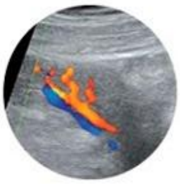

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Description of a new technique for automatic sonographic measurement of variation of head–perineum distance and angle of progression during active phase of second stage of labor

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Short title: Automatic intrapartum ultrasound measurement

Keywords: head-perineum distance, Angle of progression, intrapartum ultrasound, labour, second stage, instrumental delivery

CONTRIBUTION

What are the novel findings of this work?

We have assessed the feasibility of the automatic measurement of the variation of two highly predictive sonographic parameters during the active phase of the II stage of labour: HPD (Delta-HPD) and AoP (Delta-AoP). The software implemented in this study resulted to be as accurate as an experienced operator and to quickly provide the necessary data.

What are the clinical implications of this work?

The possibility to authomatically calculate the dynamic variation of the most commonly used sonographic indices of the fetal head station and progression, may provide accurate and fundamental data to the clinician who is managing an obstructed or protracted second stage of labour, avoiding time consuming and technique demanding examination.

ABSTRACT

Objectives

To evaluate the performance of a new ultrasound technique for the automatic assessment of the changes of the head-perineum distance (delta-HPD) and of the Angle of Progression (delta-AoP) during the active phase of the second stage of labour.

Methods

Prospective observational cohort study including singleton term pregnancies with fetuses in cephalic presentation during the active phase of the second stage of labour. Using the transperineal approach, two short video clips of 10 sec each were recorded between the rest and the acme of two expulsive efforts to measure the AoP and the HDP. The clips were processed off-line and the changes of the two measurements (delta-HDP and delta-AoP) were calculated manually by experienced sonographers and using a new automatic system. The reliability of the algorithm was evaluated by comparing the automatic and the manual measurements, which were assumed as the reference gold standard.

Results

Overall, 27 women were included. A significant correlation between the results obtained through the automated and the manual reference methods was found for both parameters (Intra-CC $_{\text{delta-HPD}}$ = 0.97; Intra-CC $_{\text{delta-AoP}}$ =0.99). The values of the coefficient of determination (r^2_{deltaHPD} = 0.98; r^2_{deltaAoP} =0.98) and the low residual errors (root mean square error $_{\text{delta-HPD}}$=1.2 mm; root mean square error $_{\text{delta-AoP}}$= 1.5°) confirm the good accuracy provided by the algorithm. The Bland-Altman analysis showed a mean difference of 0.52 mm (limits of agreement, 2.10 mm) for the delta-HPD (*p*=0.034) and of 0.35° (limits of agreement, 2.83°) for the delta-AoP (*p*=0.39).

Conclusions

The automatic assessment of delta-AoP and delta-HPD during pushing efforts is feasible. The automatic measurement of delta-AoP appears reliable when compared to gold standard measurement.

INTRODUCTION

Determining the progression of the fetal head in the birth canal under the force of maternal efforts together with the uterine contractions is often used as a variable to predict the labour outcome[1]. During this active phase, the digital evaluation 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 clinician in the management of prolonged second stage of labour[4,8]. Under such circumstances, a list of sonographic parameters has been shown to be more accurate and reproducible than digital examination in defining the fetal head station[9-15]. Among these, both the Head-Perineum Distance (HPD) and the Angle of Progression (AoP) are suggested as the gold standard measurements by the International Society of Ultrasound in Obstetrics & Gynecology (ISUOG) guidelines[16].

Rather than the absolute value obtained at rest, the dynamic change of these parameters during maternal pushing has been claimed by a recent ISUOG guideline to be helpful in assessing the progression of the head during the second stage of labour and in anticipating the outcome of instrumental vaginal delivery (IVD)[17-20]. Furthermore, the dynamic changes of these sonographic findings have proven to be useful in terms of visual coaching during the active second stage of labour[21,22].

The changes of the AoP and the HPD during the maternal pushing efforts are not routinely assessed. In fact, available evidence has not demonstrated their superiority compared to the static assessment, furthermore the evaluation of such dynamic changes may be time-consuming in contexts where a rapid decision-making process is required in order to achieve a prompt and appropriate intervention.

The aim of this study was to assess the feasibility of a new algorithm for the automated measurement of the delta-AoP and of the delta-HPD during the active phase of the second stage of labour, and to evaluate its reliability by comparing automated and gold standard manual measurements.

METHODS

This is a prospective cohort study which was conducted at the University Hospital of Parma between May 2018 and January 2019. A non-consecutive series of uncomplicated singleton term pregnancies (>37 weeks of gestation) in active labour, with fetuses in cephalic presentation, were considered eligible for the study purposes. These patients underwent the conventional labour management and, in those who consented to study enrolment, transperineal ultrasound was performed during the active phase of the second stage of labour. The ultrasound examination was performed by one of the project investigators (TG, AD, LA or NV), who was blinded to the clinical findings and not involved in the clinical management of the patient but available upon request for research purpose.

For the current research project, all the ultrasound examinations were performed using the SensUS Touch system (Amolab Srl, Lecce, Italy; www.amolab.it), an ultrasound portable device consisting of a tablet PC equipped with a 3.5-MHz convex transducer.

In each patient, a video clip was acquired transperineally, both on the axial and on the sagittal plane, with the woman in a semi-recumbent position and with the empty bladder. Each video clip acquisition encompassed one single pushing effort. The duration of the clip was set at 10 seconds with a frame rate of 8/sec (80 frames per clip).

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

Following the manual calculation, the measurement of the delta-HPD and the 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 the 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, the perineal interface) and their geometrical features on grey-scale ultrasound. The approach for the automatic segmentation is applied only to the first image frame of the sequence and includes the following steps: 1) conversion of the image into a binary map (i.e., a black-and-white image); 2) the selection of the anatomical landmarks is based on their position and geometry and on the use of dedicated filters; 3) the final "quality check" is based on global geometric considerations which 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 are used as the reference for the pattern-tracking algorithm, which is used to identify the landmark structures in the subsequent images. This includes the following steps: 1) selection of the "candidates" potentially representing the targeted anatomical landmarks 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" whose features minimize the difference with respect to the set of reference features extracted from the structure segmented in the first image.

When the analysis of the 80 frames of the sequence is completed, then the algorithm evaluates the relative position of the identified landmark structures (i.e. pubic symphysis and fetal head for the AoP, the fetal head and the perineal interface for the HPD) and calculates the AoP or the HPD in each frame. The automatic calculation of the delta-HPD and the delta-AoP represents the difference between the minimum value measured at rest and the maximum value measured at the acme of the pushing effort (Videoclips 1S-2S, Suppl. Material).

When the measurement is obtained, in order to ensure the optimal accuracy of the measurement the operator is asked whether the measurement is technically correct or whether another acquisition needs to be performed. The algorithm may require serial attempts in order to obtain optimal views for the automated measurement of the delta-HPD and of the 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 seconds for processing an entire sequence of images and providing the results.

The normality of the distribution of continuous variables was preliminary evaluated by means of the Kolmogorov-Smirnov and the Shapiro-Wilk tests and data were shown as mean $\pm$ standard deviation or as median (range) accordingly. The accuracy of the algorithm was assessed by comparing the automatic values of delta-HPD and delta-AoP with those resulting from the manual segmentation performed by an experienced operator (used as the reference). For both the considered parameters, the correlation between manual and automatic measurements was assessed through the calculation of the Intraclass Correlation Coefficient (Intra-CC), the coefficient of determination (r^2) and the RMSE (root mean square error). The significance level of systematic differences was assessed through one-sample t-test. Furthermore, agreement between the two methods was evaluated as recommended by Altman and Bland, by calculating the paired difference for each measurement and by estimating the bias and 95% limits of agreement relative to the average measurement of both methods.

The study protocol was approved by the local ethics committee of the University Hospital of Parma (270/2018/OSS/AOUPR) and a signed consent was obtained in all cases prior to enrolment.

RESULTS

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

A correlation was found between the measurements performed automatically by the algorithm and those obtained by the expert manual segmentation for both delta-HPD and delta-AoP. A very high inter-method agreement was found between the manual and the automatic calculation as shown in Table 2 and Table 3 ($Intra\text{-}CC_{delta\text{-}HPD}$= 0.97; $Intra\text{-}CC_{delta\text{-}AoP}$ = 0.99). High values of the coefficient of determination ($r^2_{delta\text{-}HPD}$ = 0.98; $r^2_{delta\text{-}AoP}$ = 0.98) and the low residual errors ($RMSE_{delta\text{-}HPD}$ = 1.2 mm, $RMSE_{delta\text{-}AoP}$ = 1.5°) confirmed the good accuracy provided by the automatic method. The measurement agreement plot demonstrated an overall mean difference in delta-HPD measurement of 0.52 ± 2.10 mm and in delta-AoP of 0.35 ± 2.8° (figure 1 and figure 2).

The analysis of the systematic difference between manual and automatic measurements showed no significant difference for the delta-AoP (p=0.39) (Table 3), whereas the automatic measurement of the delta-HPD resulted about 0.5 mm greater than the corresponding manual measurement (p=0.034) (Table 2). No case of negative values of the delta-HPD or of the delta-AoP were recorded.

DISCUSSION

The automatic calculation of the delta-HPD and of the delta-AoP during the second stage of labour is feasible and provides reliable measurements of the AoP compared to the gold standard manual reference. On the other hand, the automatic measurements yielded higher values of the delta-HPD compared to the manual ones, however this difference was deemed to be clinically not relevant.

The assessment of the progression of the fetal head in the birth canal during the pushing efforts may be performed when labour obstruction is suspected [1] or to evaluate the feasibility of an IVD[26,27]. The assessment of the fetal head descent is classically based on the digital palpation of the fetal head under maternal pushing. However, it has been demonstrated that the accuracy of the digital examination is suboptimal[2,3], particularly in the presence of caput and cranial moulding. In the last decade, transperineal ultrasound has proven to be reproducible and accurate in assessing the fetal station [9-12,28-30].

Among the different ultrasound parameters proposed, the AoP and the HPD have gained much popularity and have been increasingly used in the management of abnormal labor [4-8,17-20,31-36]. On this basis, the recent ISUOG guideline has recommended their routine measurement in the prolonged second stage of labour or before considering an 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 labour has been based on the values measured at rest. On the other hand, the sonographic assessment of the skull progression through the birth canal under maternal pushing has been proposed as an additional method to predict labour 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 others observed that a change in the AoP greater than 15° could predict the 73% of successful vaginal extraction[18]. In a recent multicentric prospective study conducted on women with prolonged second stage, the delta-HPD was found to be inversely related to the duration of the operative delivery, the risk of failure, and the need of a subsequent caesarean delivery[19].

On this ground, despite the paucity of data, a dynamic rather than a static transperineal ultrasound assessment seems more appropriate in the prediction of labour outcome.

However, the changes of the ultrasound parameters during the contractions are not routinely quantified in the clinical practice. This may be due to the fact that the online, fast and accurate calculation of the delta-AoP and/or delta-HPD during the pushing effort seems to be technically demanding also 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 which can calculate these parameters based on a pattern recognition method to identify the pubic symphysis and the fetal head. Youssef at al.[24] reported a different method for the automatic measurement of the AoP which was based on a commercially available software whose technical features are 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 herein described is able to quantify within a few seconds the relative changes of these parameters under the maternal pushing, therefore measuring the values of delta-AoP and delta-HPD referred to 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 measurements compared to the gold standard manual reference were associated with a minimal overestimation of the delta-HPD, less than 1 mm. On this basis, we do envisage that such negligible difference is of no relevance when considered in the clinical context.

The number of acquisitions performed was not recorded in this present study, however it has to be acknowledged that there may be a need of serial attempts in order to obtain optimal views for the automated measurement of the delta-HPD and of the delta-AoP.

The strengths of our study are the prospective design and the reliability of the manual analysis of the images, which was always performed by sonographers with high experience in the field of intrapartum ultrasound.

The limitations of our study are mainly related to the small number of the included cases. Therefore, even though our results are encouraging, we do envisage it is premature to declare that the method actually works. Furthermore, the relationship between the quantitative changes of the two parameters under maternal pushing is of interest but has not been intentionally investigated. As AoP and HPD need to be 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 cases of negative delta-HPD have been obtained. This is in contrast with a recent large multicentric study where a few cases of women with negative changes of the HPD under maternal pushing have been observed[19]. The authors have proposed that this may be due to inappropriate coactivation of the levator ani muscle during the maternal effort. Some authors previously reported that the inappropriate activation of the levator ani is common at term gestation[37], thus we speculate that this may occur also during the second stage.

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

In conclusion, the automatic assessment of the changes in HPD and AoP during the pushing efforts of women in the second stage of labour 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.

CONFLICT OF INTEREST: none declared.

References

1. Cunningham FG, Leveno KJ, Bloom SL, Hauth JC, Gilstrap LC III, Wenstrom KD (eds). Normal labor and delivery. In Williams Obstetrics (22nd ed). McGraw-Hill: 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**:868-74
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**:436-41.
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 wom-

en with a prolonged second stage of labor: the value of intrapartum ultrasound. *Am J Obstet Gynecol.* 2019 Oct **4.** pii: S0002-9378(19)31211-6

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**:425-9.

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**:62-9.

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 J L. 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

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 obstetricians gynaecologist. *Int J Gynaecol Obstet* 2001; **74**:69-76

27. Royal college of Obstetricians and Gynaecologists. Operative vaginal delivery. Green-top guideline no 26; Jan 2011

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. DOI 10.1111/aogs.13251. 736. DOI 10.1002/uog.6400

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 ; **4** :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.e1-193.e12.

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, LecointreL, 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.e1-189

Legends

Figure 1: Measurement agreement for the comparison of automatically - and manually -measured delta-HPD values (dotted lines identify the 95% limits of agreement).

Figure 2: Measurement agreement for the comparison of automatically - and manually -measured delta-AoP values (dotted lines identify the 95% limits of agreement).

Video clip 1S. Automatic calculation of the delta HPD (difference between the HPD measured at the acme of maternal pushing and the HPD measured at rest)

Video clip 2S. Automatic calculation of the delta AoP (difference between the AoP measured at the acme of maternal pushing and the AoP measured at rest)

Table 1 – Characteristics of the study population.

Age, years mean $\pm$ SD	33.1 $\pm$ 4.3
BMI, kg/m^2 mean $\pm$ SD	24.9 $\pm$ 5
Parity, multiparae N (%)	2/27 (7.4%)
Gestational Age, weeks^{+days} mean $\pm$ SD	39^{+1}
Occiput position at time of US acquisition N (%) - OA - OP - OT	 24 (88.9%) 2 (7.4%) 1 (3.7%)
Mode of delivery N (%) • Vaginal delivery • Cesarean section • Instrumental delivery	 18 (66.7%) 7 (26%) 2 (7.4%)
Birthweight, kilograms mean $\pm$ SD	3.3 $\pm$ 0.4

SD standard deviation; OA occiput anterior; OP occiput posterior; OT occiput transverse

Table 2: Intraclass correlation coefficient (Intra-CC) reproducibility of the measurements of the delta-HPD (n=27; the systematic difference between the automatic and manual method was assessed by means of the one-sample t-test))

Difference between the automatic and manual method to measure delta-HPD (mm)									
Intra-CC	*Mean*	95% CI *of mean*	2SD	*Lower limit*	*Upper limit*	95% CI *of lower limit*	95% CI *of upper limit*	*Range*	*P-value*
0.97	0.52	0.04 to 0.99	2.14	-1.58	2.62	-2.40 to -0.75	1.79 to 3.44	-1.78 to 2.41	0.034

Table 3**:** Intraclass correlation coefficient (Intra-CC) reproducibility of the measurements of the delta-AoP (*n*=27; the systematic difference between the automatic and manual method was assessed by means of the one-sample t-test)).

Difference between the automatic and manual method to measure delta-AoP (º)									
Intra-CC	*Mean*	95% CI *of mean*	2SD	*Lower limit*	*Upper limit*	95% CI *of lower limit*	95% CI *of upper limit*	*Range*	*P-value*
0.99	0. 35	-0.37 to 0.93	2.87	-2.54	3.09	-3.67 to -1.4	1.95 to 4.23	-2.6 to 2.56	0.39

Figure 1: Measurement agreement for the comparison of automatically - and manually -measured delta-HPD values (dotted lines identify the 95% limits of agreement).

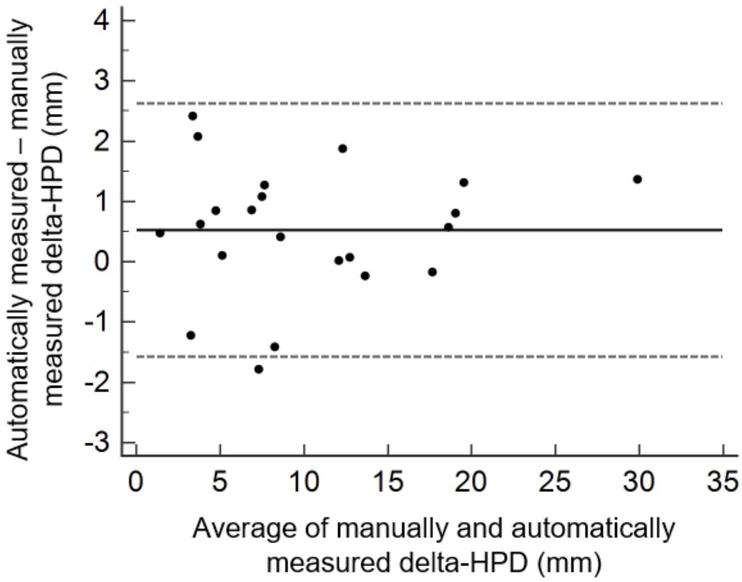

Figure 2: Measurement agreement for the comparison of automatically - and manually -measured delta-AoP values (dotted lines identify the 95% limits of agreement).