



Automatic measurement of head-perineum distance during intrapartum ultrasound: description of the technique and preliminary results

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Keywords:	childbirth, intrapartum ultrasound, labor monitoring, head-perineum distance, transperineal ultrasound

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Manuscripts

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4 **1 Automatic measurement of head-perineum distance during intrapartum ultrasound:**
5 **2 description of the technique and preliminary results**

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Abstract

Objectives:

To evaluate the accuracy and reliability of a new ultrasound technique for the automatic assessment of the head-perineum distance (HPD) during childbirth.

Methods:

HPD was measured on a total of 40 acquisition sessions in 30 laboring women both automatically by an innovative algorithm and manually by trained sonographers, assumed as goldstandard.

Results:

A significant correlation was found between manual and automatic measurements (Intra-CC = 0.994). High values of the coefficient of determination ($r^2 = 0.98$) and low residual errors: RMSE = 2.01 mm (4.9%) were found.

Conclusions:

The automatic algorithm for the assessment of the HPD represents a reliable technique.

Keywords: childbirth; intrapartum ultrasound; labor monitoring; medical decision support; head-perineum distance; ultrasonic imaging, transperineal ultrasound, automatic measurement

44 INTRODUCTION

45 Intrapartum ultrasound is increasingly performed in the routine practice, with the aim of
46 supporting the clinical skills with a more objective and reproducible assessment tool ¹⁻³. The
47 concept that fetal head position and station are more precisely identified by ultrasound than by
48 clinical examinations is well established ⁴⁻⁷. A better performance of the former approach for
49 the prediction and the diagnosis of labor arrest is also acknowledged ⁸⁻⁹. Moreover, it has been
50 demonstrated that ultrasound imaging is valuable in predicting the outcome of instrumental
51 vaginal delivery ¹⁰⁻¹⁴.

52 When using ultrasound in labor, the transperineal approach is commonly performed for
53 the evaluation of the fetal head rotation and station¹⁵. The latter can be established by means
54 of a series of quantitative parameters that have been proposed to define objectively the level
55 of the presenting part within the birth canal ^{1-3,16-18}. Eggebø *et al.* ² proposed the head-
56 perineum distance (HPD), defined as the shortest distance from the outer bony limit of fetal
57 skull to the perineum, while Barbera *et al.*¹ introduced the progression angle (PA), which is
58 the angle between the long axis of the pubic symphysis and the line starting from the distal
59 point of the symphysis and running tangentially to the leading part of the fetal skull.

60 A potential limitation to the use of labor ultrasound is represented by the lack of a
61 simple method for the measurement of the sonographic parameters that seem relevant to
62 refine the clinical management of labor. Actually, new approaches for the automatic
63 measurement of PA during labor have been recently proposed¹⁹⁻²¹, but, to the best of our
64 knowledge, there are still no examples of similar systems dedicated to HPD assessment.

65 The aim of this feasibility study was to preliminarily assess the accuracy of a new
66 algorithm for the automatic measurement of HPD during the second stage of labor.

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METHODS

Patients

A non-consecutive series of pregnant women in the active second stage of labor were recruited for the study purpose. They were eligible if they carried a singleton pregnancy with fetuses in cephalic presentation, absence of documented fetal malformations and no history of previous Caesarean sections. The study was conducted at the Maternity Hospital of the Department of Medicine and Surgery of the University of Parma between February 2018 and February 2019. The enrolled women underwent the conventional labor management according to standard local procedures. 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.

Ultrasound assessment

Ultrasound acquisitions were performed using the SensUS Touch system (Amolab Srl, Lecce, Italy; www.amolab.it), an ultrasound portable system consisting of a tablet PC equipped with a 3.5-MHz convex transducer. Each acquisition was performed with the woman in a semirecumbent position, with legs flexed at the hips and knees at 45° and 90°, respectively¹⁵. The probe was transversally placed over the posterior fourchette, with the operator exerting a firm pressure but without creating discomfort to the patient. The transducer was angled until the skull contour appeared as clear as possible, indicating that the ultrasound beam was perpendicular to the fetal skull. All acquisitions were performed after the uterine contraction, within 1 minute after the peak intensity. When two different sonographic acquisitions were performed on the same patient, the corresponding time interval was variable and always established by the clinical staff.

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3 92 Once the operator correctly identified the anatomical landmarks, a 5-second acquisition
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5 93 was started: 80 B-mode images were acquired (frame rate ~16 fps) and stored for the
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7 94 subsequent off-line analysis, in which each frame was automatically analysed by the
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9 95 algorithm. The algorithm automatically processed the images in order to calculate the HPD.
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12 96 These results were compared with those manually obtained by two experienced sonographers
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14 97 (AD and NV) who were blinded to the algorithm outcomes and who performed the
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16 98 measurements off-line on the same images analysed by the algorithm. Manual results obtained
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18 99 by the two different trained sonographers were assumed as the gold standard reference for the
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20 100 automated measurements.

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24 101 The images collected during the first acquisition were processed through the automatic
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26 102 segmentation algorithm and a pattern tracking algorithm was used to analyse the images
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28 103 associated to the possible subsequent sessions acquired on the same patient.

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32 33 105 **Automatic HPD calculation**

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35 106 The algorithm computed the HPD value as the distance between the horizontal line
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37 107 tangent to the outer bony limit of fetal skull and the horizontal line drawn at the midpoint of
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39 108 the probe-tissue interface, corresponding to the maternal perineum (Figure 1).

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42 109 To optimize the reliability of the automatic measurement and calculation procedure, the
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44 110 operators who performed the image acquisitions were asked to orientate the probe in a way
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46 111 such to display the fetal head in the central part of the field of view of ultrasound.

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49 112 A schematic illustration of the algorithm is reported in Figure 2.

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51 113 Each acquired image was analysed through the steps described below:

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53 114 (1) *Image validation*, based on grey level and geometrical feature analysis. The aim of this
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55 115 phase was to verify the image suitability for the subsequent processing steps and to
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57 116 discard the images of insufficient quality;

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3 117 (2) Search for raw bone structures, based only on pixel cluster positions and their grey
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5 118 level intensities (the clusters of pixels identified in this step may include artefacts due
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7 to noise);
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10 120 (3) Fetal head detection, which occurred in two different ways, depending on the fact that
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12 121 the considered image belonged to the first acquisition session or to a subsequent
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14 122 acquisition session. In the former case, fetal head detection was accomplished through
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16 123 morphological image filters aimed at the automatic identification of the landmark bone
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18 124 structure, whereas in the latter case a pattern tracking approach was employed;
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21 125 (4) Detection of the perineal interface central point, based on the geometrical features of
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23 the probe;
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26 127 (5) Co-registration of coordinates for fetal head and perineal interface, aimed at the
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28 128 knowledge of the mutual position of the identified references;
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31 129 (6) HPD calculation, as the distance between the central point identified on the semi-arc
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33 130 of the perineal maternal interface, and the horizontal axis passing from the leading
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35 131 edge of fetal skull. It represents the part of the birth canal yet to be passed by the fetus.

37 132 This process was applied to all the acquisition sessions and the obtained results were used to
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39 133 select a reference image as representative of the whole session. Actually, for each image
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41 134 belonging to the considered acquisition session, the algorithm calculated the values of HPD
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43 135 and the coordinates of the fetal head (centre, radius). The reference image was chosen as the
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45 136 one having the values of these parameters closest to the corresponding average values.
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49 137 Data analyses was performed on a laptop equipped with an Intel i7 Core™ i7-3610QM
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51 138 processor at 2.3 GHz (8 GB of RAM, 64 bits). Using the approach validated in a previous
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53 139 paper¹⁹, the pattern tracking algorithm demonstrated again to be a faster approach.
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58 141 **Statistical analysis**

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3 142 The correlation between the manual and the automatic measurements of the HPD was
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5 143 assessed through the calculation of the Intraclass Correlation Coefficient (Intra-CC), the
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7 144 coefficient of determination (r^2) and the RMSE (root mean square error). Furthermore, the
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9 145 agreement between the two methods was also assessed by calculating the paired difference for
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11 146 each measurement and by estimating the bias and 95% limits of agreement relative to the
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13 147 average measurement of both methods.
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18 148 **RESULTS**

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20 149 A cohort of 30 laboring women at the beginning of the active phase of the second stage of
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22 150 labor was recruited. The median gestational age at the recruitment was 40 weeks (range 35-
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24 151 41). Most of the women were nulliparous (24/30 or 80%), median BMI was 25 (16-40) and
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26 152 the median maternal age was 35 years (27-45). Overall, 23 women (77%) achieved
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28 153 spontaneous vaginal delivery, while instrumental vaginal delivery or Cesarean delivery were
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30 154 performed in 5 (16%) and in 2 cases (7%) respectively. A total of 40 transperineal
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32 155 sonographic acquisitions were carried out on the study population. The number of ultrasound
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34 156 acquisitions for each patient varied from 1 to 4: the majority of patients (24/30) were
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36 157 submitted to a single acquisition, 2 acquisitions or more were performed in the remaining six
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38 158 women. Transperineal measurement of the HPD was well tolerated by all the patients also
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40 159 thanks to the short duration of sonographic acquisitions. Indeed, the single sonographic
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42 160 acquisition lasted 5 seconds, with the probe in a fixed transversal transperineal position, and
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44 161 was followed by 20 seconds of fully automatic image processing.
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50 162 A statistically significant correlation was found between the HPD measurements performed
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52 163 by the algorithm and those obtained by the expert manual segmentation. The results of the
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54 164 Inter-method agreement analysis are shown in Table 1 in which we can observe the optimal
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56 165 Intra-CC value of 0.994 and the bias and 95% limits of agreement relative to the average
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58 166 measurement of both methods (0.18 ± 3.16 mm), whose actual meaning is graphically
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3 167 illustrated in the measurement agreement plot (Figure 3). Finally the high values of the
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5 168 coefficient of determination ($r^2 = 0.98$) and the low residual error, RMSE = 2.01 mm (4.9%),
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7 169 confirmed the good accuracy provided by the automatic method.
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12 171 **DISCUSSION**

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14 172 Intrapartum ultrasound has been introduced in the last decade to evaluate the fetal head
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16 173 descent during labor^{8-9,16-17,22-23}. Different sonographic parameters have proved to be more
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18 174 reproducible and reliable than digital examination in assessing the fetal station^{4-7,24}. Among
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20 175 them, the HPD and the AoP have been demonstrated to be more valuable than clinical skills in
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22 176 predicting the labor outcome and the failure of operative vaginal delivery^{-10-13,24-29}. Based on
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24 177 the available literature, the routine measurement of the HPD has been recommended by the
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26 178 ISUOG guidelines on labor ultrasound before considering or performing an instrumental
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28 179 vaginal delivery¹⁵. However, the use of intrapartum transperineal ultrasound in clinical routine
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30 180 is still limited, mainly because of the lack of expertise in obtaining the proper images and in
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32 181 measuring the sonographic parameters. More recently, newly developed automated devices
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34 182 available in research settings have offered the opportunity to measure the fetal head
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36 183 progression in labor¹⁹⁻²¹. Such tools are operator-independent and in some instances may
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38 184 optimize the acquisition of the sonographic parameters of interest. With some devices more
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40 185 than one parameter can be obtained and calculated at once on the same scanning plane, so that
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42 186 the results of the ultrasound study can be more easily integrated and interpreted for clinical
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44 187 purposes.
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51 188 The present study introduced a new methodology for the automatic measurement of the
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53 189 HPD during labor, according to the scanning technique originally proposed by Eggebø *et al.*²
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55 190 The algorithm for HPD calculation was constructed in accordance with a previously
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3 191 established approach which had been used for automatic assessment of the AoP and had been
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5 192 validated in a previous study¹⁹.

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8 193 More specifically, automatic segmentation and tracking algorithms were used to
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10 194 identify the reference anatomical landmarks which allow the automatic measurement of the
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12 195 HPD. This technique was applied to 40 transperineal axial ultrasound acquisitions and the
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14 196 corresponding results were compared with those obtained through the manual tracking of the
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16 197 same anatomic landmarks performed by an experienced operator. A strong and statistically
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18 198 significant correlation was found between the two methods.

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21 199 In principle, we cannot exclude that during the image acquisition a small systematic
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23 200 error in the HPD measurement could be introduced by the variable degree of external
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25 201 compression of the soft tissues. However, considering that a firm pressure during the
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27 202 acquisition was applied, we can assume a good reproducibility of the measures.

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30 203 During the implementation of the algorithm, in fact, a major simplification has been
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32 204 intentionally made. The fetal skull was approximated to a circumference, which is not strictly
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34 205 correct, but in order to calculate the HPD value, only the leading edge of the fetal skull has to
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36 206 be considered, and therefore we can assume this as a reasonable approximation. Furthermore,
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38 207 the same assumption had been made in the previous study in which the accuracy and
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40 208 reliability of a new ultrasound technique for automatic calculation of the progression angle
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42 209 during labor monitoring was demonstrated¹⁹.

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47 210 The fact that the fetal head was not always exactly in the center of the ultrasound image
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49 211 is not likely to have affected the HPD measurement, since the lines drawn by the software
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51 212 guaranteed that the distance from the leading edge of fetal skull and the central point of the
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53 213 maternal perineal interface was always correctly measured (Figure 1b).

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57 214 In conclusion, our work has shown that the automated measurement of the HPD during labor
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59 215 is feasible and shows good correlation with gold standard manual measurement performed by
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3 216 senior experts. This newly developed algorithm has the potential to support clinicians in
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5 217 performing intrapartum ultrasound, which has been recently suggested to improve the the
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8 218 management of labor.
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44 229 **Frusca Tiziana**¹; analysing data
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47 230 **Ghi Tullio**¹ analysing data, writing the manuscript, devising the study project
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54 232 Statement of Ethics
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56 233 The research was conducted ethically in accordance with the [World Medical Association](#)
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58 234 [Declaration of Helsinki](#).
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3 235 **Disclosure Statement**
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6 236 **CONFLICTS OF INTEREST**
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10 237 F. Conversano, M. Di Paola, and S. Casciaro are shareholders of Amolab S.r.l., a National
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12 238 Research Council Spin-off company that may or may not benefit from the results of this study
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Tables

Table 1: Analysis of the differences in HPD measurements between expert manual segmentation and automatic algorithm ($n=40$)

<i>Difference between the two methods (mm)</i>									
<i>ICC</i>	<i>Mean</i>	<i>95% CI of mean</i>	<i>1.96 SD</i>	<i>Lower limit</i>	<i>Upper limit</i>	<i>95% CI of lower limit</i>	<i>95% CI of upper limit</i>	<i>Range</i>	
0.994	0.18	-0.33 to 0.67	3.16	-2.98	3.34	-3.86 to -2.09	2.45 to 4.22	-3.65 to 2.72	

Figures legends:

Fig. 1. a) Automatic segmentation of a typical ultrasound image acquired transperineally on the axial plane: the HPD value is identified by the length of the vertical segment between the dotted lines; b) Example of automatic image segmentation when the fetal head was not in the center of the ultrasound image

Fig. 2. Schematic representation of the adopted algorithm for HPD calculation.

Fig. 3. Measurement agreement plot for the comparison of manually- and automatically-measured HPD values (dotted lines identify the 95% limits of agreement).

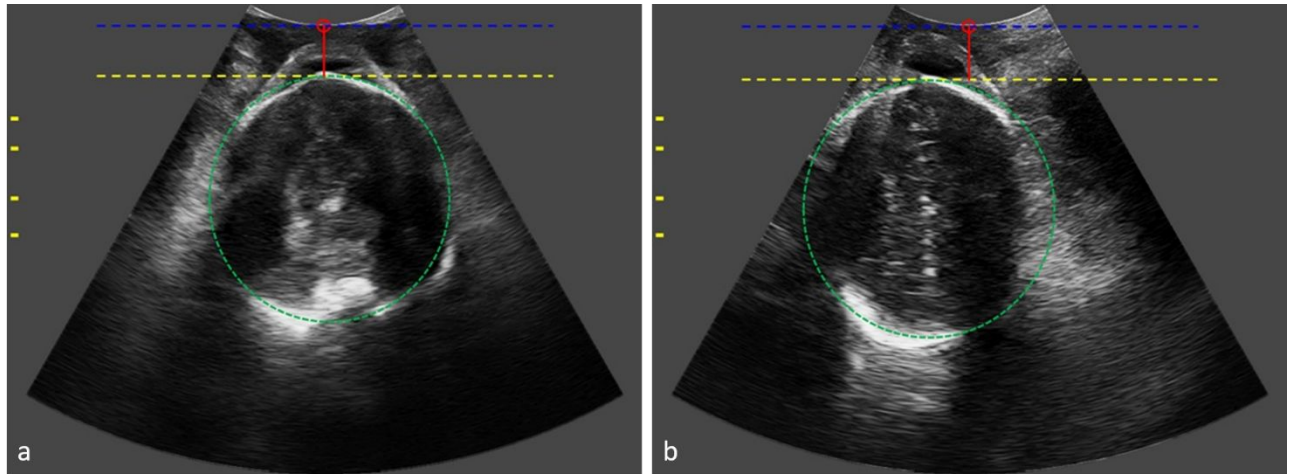


Fig. 1. a) Automatic segmentation of a typical ultrasound image acquired transperineally on the axial plane: the HPD value is identified by the length of the vertical segment between the dotted lines; b) Example of automatic image segmentation when the fetal head was not in the center of the ultrasound image

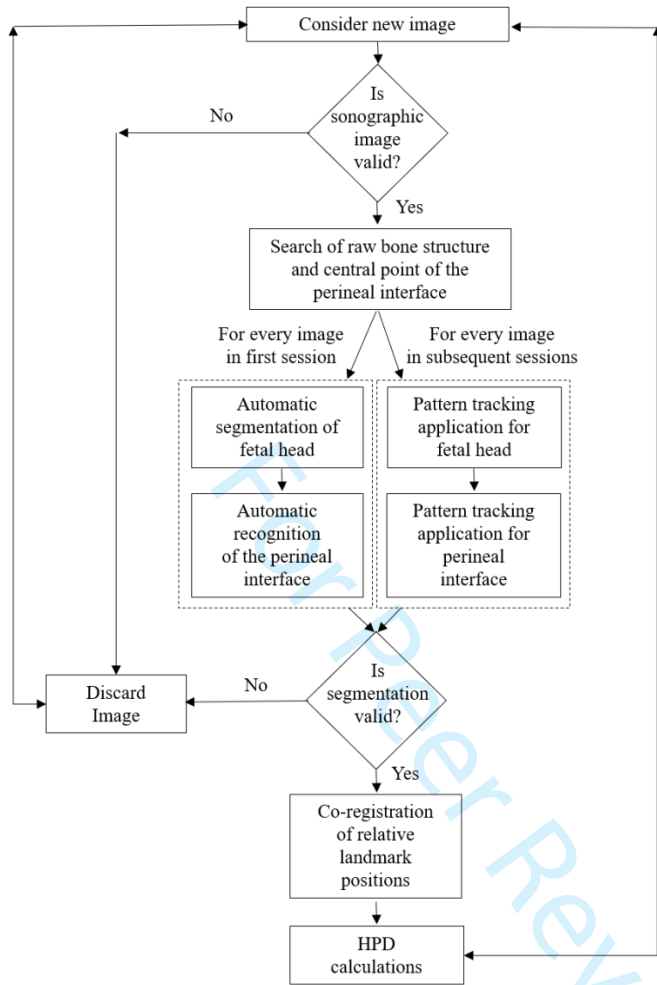


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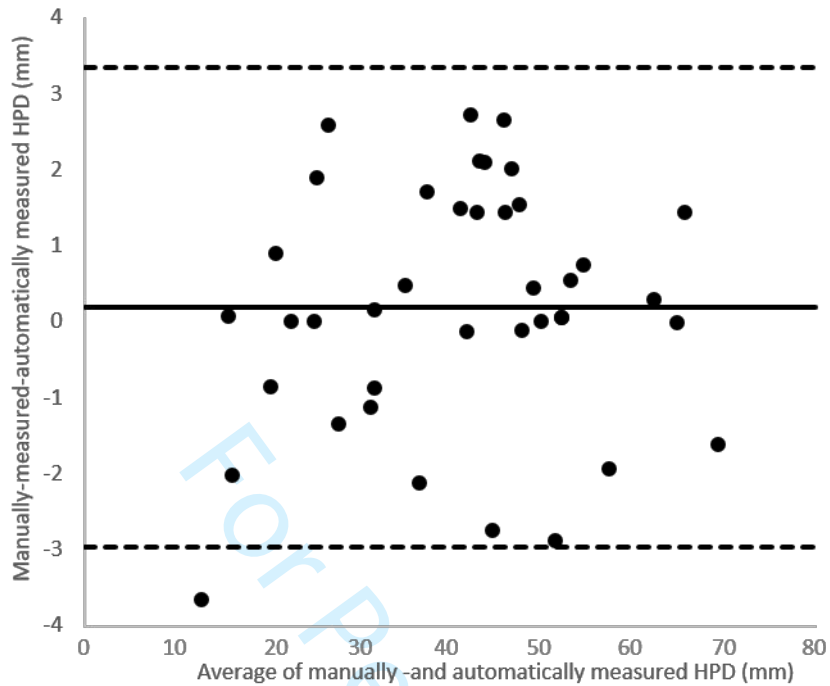


Fig. 3. Measurement agreement plot for the comparison of manually- and automatically-measured HPD values (dotted lines identify the 95% limits of agreement).

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4 **1 Automatic measurement of head-perineum distance during intrapartum ultrasound:**
5 **2 description of the technique and preliminary results**

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60 51**Abstract****Objectives:**

To evaluate the accuracy and reliability of a new ultrasound technique for the automatic assessment of the head-perineum distance (HPD) during childbirth.

Methods:

HPD was measured on a total of 40 acquisition sessions in 30 laboring women both automatically by an innovative algorithm and manually by trained sonographers, assumed as goldstandard.

Results:

A significant correlation was found between manual and automatic measurements (Intra-CC = 0.994). High values of the coefficient of determination ($r^2 = 0.98$) and low residual errors: RMSE = 2.01 mm (4.9%) were found.

Conclusions:

The automatic algorithm for the assessment of the HPD represents a reliable technique.

Keywords: childbirth; intrapartum ultrasound; labor monitoring; medical decision support; head-perineum distance; ultrasonic imaging, transperineal ultrasound, automatic measurement

44 INTRODUCTION

45 Intrapartum ultrasound is increasingly performed in the routine practice, with the aim of
46 supporting the clinical skills with a more objective and reproducible assessment tool ¹⁻³⁵. The
47 concept that fetal head position and station are more precisely identified by ultrasound than by
48 clinical examinations is well established ⁴⁶⁻⁷⁴⁰. A better performance of the former approach
49 for the prediction and the diagnosis of labor arrest is also acknowledged ⁸⁻⁹¹¹⁻¹⁵. Moreover, it
50 has been demonstrated that ultrasound imaging is valuable in predicting the outcome of
51 instrumental vaginal delivery ¹⁰⁻¹⁴¹⁶⁻²⁰.

52 When using ultrasound in labor, the transperineal approach is commonly performed for
53 the evaluation of the fetal head rotation and station ¹⁵²¹. The latter can be established by means
54 of a series of quantitative parameters that have been proposed to define objectively the level
55 of the presenting part within the birth canal ^{1-3,165-18,14,22}. Eggebø *et al.* ² proposed the head-
56 perineum distance (HPD), defined as the shortest distance from the outer bony limit of fetal
57 skull to the perineum, while Barbera *et al.* ¹ introduced the progression angle (PA), which is
58 the angle between the long axis of the pubic symphysis and the line starting from the distal
59 point of the symphysis and running tangentially to the leading part of the fetal skull.

60 A potential limitation to the use of labor ultrasound is represented by the lack of a
61 simple method for the measurement of the sonographic parameters that seem relevant to
62 refine the clinical management of labor. Actually, new approaches for the automatic
63 measurement of PA during labor have been recently proposed ¹⁹⁻²¹²³⁻²⁴, but, to the best of our
64 knowledge, there are still no examples of similar systems dedicated to HPD assessment.

65 The aim of this feasibility study was to preliminarily assess the accuracy of a new
66 algorithm for the automatic measurement of HPD during the second stage of labor.

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56 68 **METHODS**7
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9 69 **Patients**

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11 70 A non-consecutive series of pregnant women in the active second stage of labor were
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13 71 recruited for the study purpose. They were eligible, if they carried a singleton pregnancy with
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15 72 fetuses in cephalic presentation, absence of documented fetal malformations and no history of
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17 73 previous Caesarean sections. The study was conducted at the Maternity Hospital of the
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19 74 Department of Medicine and Surgery of the University of Parma between February 2018 and
20
21 75 February 2019. The enrolled women underwent the conventional labor management
22
23 76 according to standard local procedures. The study protocol was approved by the local ethics
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25 77 committee of the University Hospital of Parma (270/2018/OSS/AOUPR) and a signed
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27 78 consent was obtained in all cases prior to enrolment.
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34 80 **Ultrasound assessment**

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36 81 Ultrasound acquisitions were performed using the SensUS Touch system (Amolab Srl,
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38 82 Lecce, Italy; www.amolab.it), an ultrasound portable system consisting of a tablet PC
39
40 83 equipped with a 3.5-MHz convex transducer. Each acquisition was performed with the
41
42 84 woman in a semirecumbent position, with legs flexed at the hips and knees at 45° and 90°,
43
44 85 respectively ¹⁵²⁴. The probe was transversally placed over the posterior fourchette, with the
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46 86 operator exerting a firm pressure but without creating discomfort to the patient. The
47
48 87 transducer was angled until the skull contour appeared as clear as possible, indicating that the
49
50 88 ultrasound beam was perpendicular to the fetal skull. All acquisitions were performed after
51
52 89 the uterine contraction, within 1 minute after the peak intensity. When two different
53
54 90 sonographic acquisitions were performed on the same patient, the corresponding time interval
55
56 91 was variable and always established by the clinical staff.
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1
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3 92 Once the operator correctly identified the anatomical landmarks, a 5-second acquisition
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5 93 was started: 80 B-mode images were acquired (frame rate ~16 fps) and stored for the
6
7 94 subsequent off-line analysis, in which each frame was automatically analysed by the
8
9 95 algorithm. The algorithm automatically processed the images in order to calculate the HPD.
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11
12 96 These results were compared with those manually obtained by two experienced sonographers
13
14 97 (AD and NV) who were blinded to the algorithm outcomes and who performed the
15
16 98 measurements off-line on the same images analysed by the algorithm. Manual results obtained
17
18 99 by the two different trained sonographers were assumed as the gold standard reference for the
19
20 100 automated measurements.

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24 101 The images collected during the first acquisition were processed through the automatic
25
26 102 segmentation algorithm and a pattern tracking algorithm was used to analyse the images
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28 103 associated to the possible subsequent sessions acquired on the same patient.
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32 33 105 **Automatic HPD calculation**

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35 106 The algorithm computed the HPD value as the distance between the horizontal line
36
37 107 tangent to the outer bony limit of fetal skull and the horizontal line drawn at the midpoint of
38
39 108 the probe-tissue interface, corresponding to the maternal perineum (Figure_1).
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42 109 To optimize the reliability of the automatic measurement and calculation procedure, the
43
44 110 operators who performed the image acquisitions were asked to orientate the probe in a way
45
46 111 such to display the fetal head in the central part of the field of view of ultrasound.
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49 112 A schematic illustration of the algorithm is reported in Figure 2.

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51 113 Each acquired image was analysed through the steps described below:

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53 114 (1) *Image validation*, based on grey level and geometrical feature analysis. The aim of this
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55 115 phase was to verify the image suitability for the subsequent processing steps and to
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57 116 discard the images of insufficient quality;
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3 117 (2) Search for raw bone structures, based only on pixel cluster positions and their grey
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5 118 level intensities (the clusters of pixels identified in this step may include artefacts due
6
7 to noise);
8 119
9
10 120 (3) Fetal head detection, which occurred in two different ways, depending on the fact that
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12 121 the considered image belonged to the first acquisition session or to a subsequent
13
14 122 acquisition session. In the former case, fetal head detection was accomplished through
15
16 123 morphological image filters aimed at the automatic identification of the landmark bone
17
18 124 structure, whereas in the latter case a pattern tracking approach was employed;
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20 125 (4) Detection of the perineal interface central point, based on the geometrical features of
21
22 126 the probe;
23
24 127 (5) Co-registration of coordinates for fetal head and perineal interface, aimed at the
25
26 128 knowledge of the mutual position of the identified references;
27
28 129 (6) HPD calculation, as the distance between the central point identified on the semi-arc
29
30 130 of the perineal maternal interface, and the horizontal axis passing from the leading
31
32 131 edge of fetal skull. It represents the part of the birth canal yet to be passed by the fetus.

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37 132 This process was applied to all the acquisition sessions and the obtained results were used to
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39 133 select a reference image as representative of the whole session. Actually, for each image
40
41 134 belonging to the considered acquisition session, the algorithm calculated the values of HPD
42
43 135 and the coordinates of the fetal head (centre, radius). The reference image was chosen as the
44
45 136 one having the values of these parameters closest to the corresponding average values.

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49 137 ~~Additional details are provided in the supplementary material of this article.~~

50
51 138 Data analyses was performed on a laptop equipped with an Intel i7 Core™ i7-3610QM
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53 139 processor at 2.3 GHz (8 GB of RAM, 64 bits). Using the approach validated in a previous
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55 140 paper¹⁹²², the pattern tracking algorithm demonstrated again to be a faster approach.

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142 **Statistical analysis**

143 The correlation between the manual and the automatic measurements of the HPD was
144 assessed through the calculation of the Intraclass Correlation Coefficient (Intra-CC), the
145 coefficient of determination (r^2) and the RMSE (root mean square error). Furthermore, the
146 agreement between the two methods was also assessed by calculating the paired difference for
147 each measurement and by estimating the bias and 95% limits of agreement relative to the
148 average measurement of both methods.

149 **RESULTS**

150
151 A cohort of 30 laboring women at the beginning of the active phase of the second stage of
152 labor was recruited. ~~The features of the population chosen for this study are reported in table~~
153 ~~1-. The median gestational age at the recruitment was 40 weeks (range 35-41). Most of the~~
154 ~~women were nulliparous (24/30 or 80%), median BMI was 25 (16-40) and the median~~
155 ~~maternal age was 35 years (27-45). Overall, 23 women (77%) achieved spontaneous vaginal~~
156 ~~delivery, while instrumental vaginal delivery or Cesarean delivery were performed in 5 (16%)~~
157 ~~and in 2 cases (7%) respectively.~~

158 A total of 40 transperineal sonographic acquisitions were carried out on the study population.
159 The number of ultrasound acquisitions for each patient varied from 1 to 4: ~~the majority of~~
160 ~~patients (24/30) were submitted to a single acquisition, 2 acquisitions or more were performed~~
161 ~~in the remaining six women as shown on Table 2.~~ Transperineal measurement of the HPD
162 was well tolerated by all the patients also thanks to the short duration of sonographic
163 acquisitions. Indeed, the single sonographic acquisition lasted 5 seconds, with the probe in a
164 fixed transversal transperineal position, and was followed by 20 seconds of fully automatic
165 image processing.

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3 166 A statistically significant correlation was found between the HPD measurements performed
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5 167 by the algorithm and those obtained by the expert manual segmentation. The results of the
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7 Inter-method agreement analysis are ~~Inter-method agreement~~ shown in Table 1 in which we
8
9 can observe the optimal Intra-CC value of 0.994 and the bias and 95% limits of agreement
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11 relative to the average measurement of both methods (0.18 + 3.16 mm), whose actual
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13 meaning is graphically illustrated in the measurement agreement plot (Figure 3). Finally the
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15 high values of the coefficient of determination ($r^2 = 0.98$) and the low residual error, RMSE =
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17 2.01 mm (4.9%), confirmed the good accuracy provided by the automatic method. The
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19 measurement agreement plot (Figure 3) demonstrated an overall mean difference in HPD
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21 measurement of 0.18 ± 3.16 mm.
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177 DISCUSSION

178 Intrapartum ultrasound has been introduced in the last decade to evaluate the fetal head
179 descent during labor ^{8-9,16-17,22-23,11-15,25,26}. Different sonographic parameters have proved to be
180 more reproducible and reliable than digital examination is assessing the fetal station ^{4-7,24-5,27}.
181 Among them, the HPD and the AoP have been demonstrated to be more valuable than clinical
182 skills in predicting the labor outcome and the failure of operative vaginal delivery ^{16-19,27-30-10-}
183 ^{13,24-29}. Based on the available literature, the routine measurement of the HPD has been
184 recommended by the ISUOG guidelines on labor ultrasound before considering or performing
185 an instrumental vaginal delivery ^{15,24}. However, the use of intrapartum transperineal ultrasound
186 in clinical routine is still limited, mainly because of the lack of expertise in obtaining the
187 proper images and in measuring the sonographic parameters. More recently, newly developed
188 automated devices available in research settings have offered the opportunity to measure the
189 fetal head progression in labor ^{23-24,19-21}. Such tools are operator-independent and in some
190 instances may optimize the acquisition of the sonographic parameters of interest. With some

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3 191 devices more than one parameter can be obtained and calculated at once on the same scanning
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5 192 plane, so that the results of the ultrasound study can be more easily integrated and interpreted
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8 193 for clinical purposes.

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10 194 The present study introduced a new methodology for the automatic measurement of the
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12 195 HPD during labor, according to the scanning technique originally proposed by Eggebø *et al.*²
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14 196 The algorithm for HPD calculation was constructed in accordance with a previously
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16
17 197 established approach which had been used for automatic assessment of the AoP and had been
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19 198 validated in a previous study ¹⁹²³.

20
21 199 More specifically, automatic segmentation and tracking algorithms were used to
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23
24 200 identify the reference anatomical landmarks which allow the automatic measurement of the
25
26 201 HPD. This technique was applied to 40 transperineal axial ultrasound acquisitions and the
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28 202 corresponding results were compared with those obtained through the manual tracking of the
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31 203 same anatomic landmarks performed by an experienced operator. A strong and statistically
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33 204 significant correlation was found between the two methods.

34
35 205 In principle, we cannot exclude that during the image acquisition a small systematic
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37 206 error in the HPD measurement could be introduced by the variable degree of external
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40 207 compression of the soft tissues. However, considering that a firm pressure during the
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42 208 acquisition was applied, we can assume a good reproducibility of the measures.

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44 209 During the implementation of the algorithm, in fact, a major simplification has been
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46
47 210 intentionally made. The fetal skull was approximated to a circumference, which is not strictly
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49 211 correct, but in order to calculate the HPD value, only the leading edge of the fetal skull has to
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51 212 be considered, and therefore we can assume this as a reasonable approximation. Furthermore,
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54 213 the same assumption had been made in the previous study in which the accuracy and
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56 214 reliability of a new ultrasound technique for automatic calculation of the progression angle
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58 215 during labor monitoring was demonstrated¹⁹.

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3 216 The fact that the fetal head was not always exactly in the center of the ultrasound image
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5 217 is not likely to have affected the HPD measurement, since the lines drawn by the software
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7 218 guaranteed that the distance from the leading edge of fetal skull and the central point of the
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10 219 maternal perineal interface was always correctly measured (Figure [1b4](#)).

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13 220 In conclusion, our work has shown that the automated measurement of the HPD during labor
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15 221 is feasible and shows good correlation with gold standard manual measurement performed by
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17 222 senior experts. This newly developed algorithm has the potential to support clinicians in
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19
20 223 performing intrapartum ultrasound, which has been ~~been~~ recently suggested to improve the
21
22 224 the management of labor.

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28
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31
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51 233 **Di Paola Marco**²; collecting data

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54 234 **Sergio Casciaro**², analysing data, collecting data

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57 235 **Frusca Tiziana**¹; analysing data

236 **Ghi Tullio**¹ analysing data, writing the manuscript, [devising the study project](#)

237

238 Statement of Ethics

239 The research was conducted ethically in accordance with the [World Medical Association](#)

240 [Declaration of Helsinki](#).

241 **Disclosure Statement**

242 CONFLICTS OF INTEREST

243 F. Conversano, M. Di Paola, and S. Casciaro are shareholders of Amolab S.r.l., a National
244 Research Council Spin-off company that may or may not benefit from the results of this study

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366 Tables

367 **Table 1:** Characteristics of the study group (n=30)

368
 369 **Table 2:** Distribution of the 40 performed acquisition sessions among the 30 enrolled
 370 patients.

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 372 **Table 13:** [Analysis of the differences in Intra-CC reproducibility of HPD](#)
 373 [measurements between expert manual segmentation and automatic algorithm \(n=40\)](#)

Difference between the two methods (mm)								
ICC	Mean	95% CI of mean	1.96 SD	Lower limit	Upper limit	95% CI of lower limit	95% CI of upper limit	Range
0.994	0.18	-0.33 to 0.67	3.16	-2.98	3.34	-3.86 to -2.09	2.45 to 4.22	-3.65 to 2.72

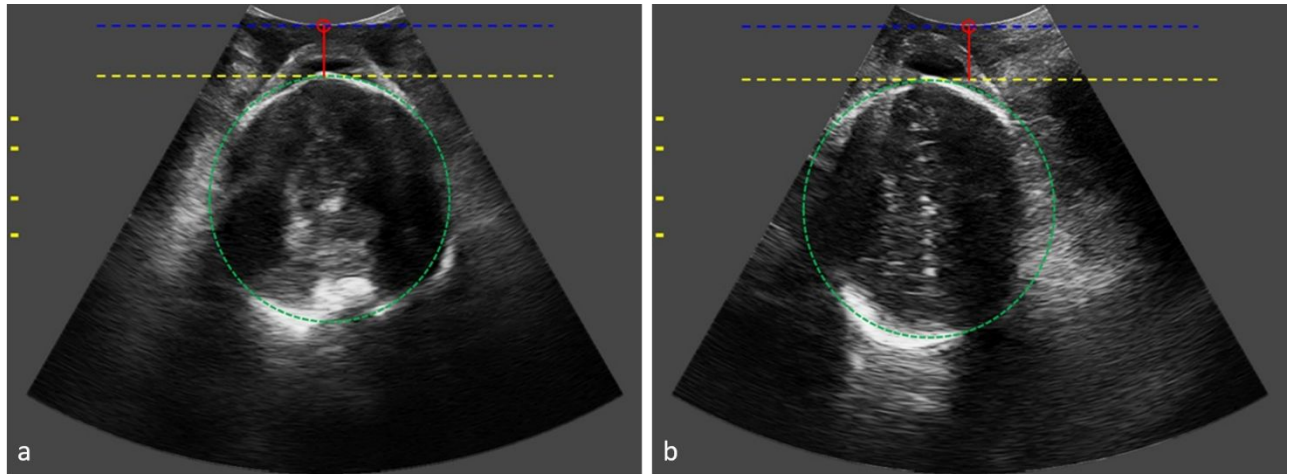
374
 375 **Figures legends:**

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3 376 **Fig. 1. a)** Automatic segmentation of a typical ultrasound image acquired
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5 377 transperineally on the axial plane: the HPD value is identified by the length of the vertical
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8 378 segment between the dotted lines; b)- Example of automatic image segmentation when the
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10 379 fetal head was not in the center of the ultrasound image

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12 380 **Fig. 2.** Schematic representation of the adopted algorithm for HPD calculation.

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14 381 **Fig. 3.** Measurement agreement plot for the comparison of manually- and
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16 382 automatically-measured HPD values (dotted lines identify the 95% limits of agreement).

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18
19 383 ~~**Fig. 4:** Steps for the automatic identification of fetal head in a typical ultrasound~~
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21 384 ~~image frame: (a,b) 'raw' identification of fetal head upper (a) and lower (b) edges, according~~
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23 ~~to pixel position in the image and to their gray-level values, and conversion to a binary map;~~
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25 ~~(c,d) median filter application and morphological evaluation on fetal head upper (c) and lower~~
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27 ~~(d) edges; (e,f) hole-filling for fetal head upper (e) and lower (f) edges; (g) merging of fetal~~
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29 ~~head structures; (h) determination of fetal head center and radius.~~
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Fig. 1. a) Automatic segmentation of a typical ultrasound image acquired transperineally on the axial plane: the HPD value is identified by the length of the vertical segment between the dotted lines; **b)** Example of automatic image segmentation when the fetal head was not in the center of the ultrasound image

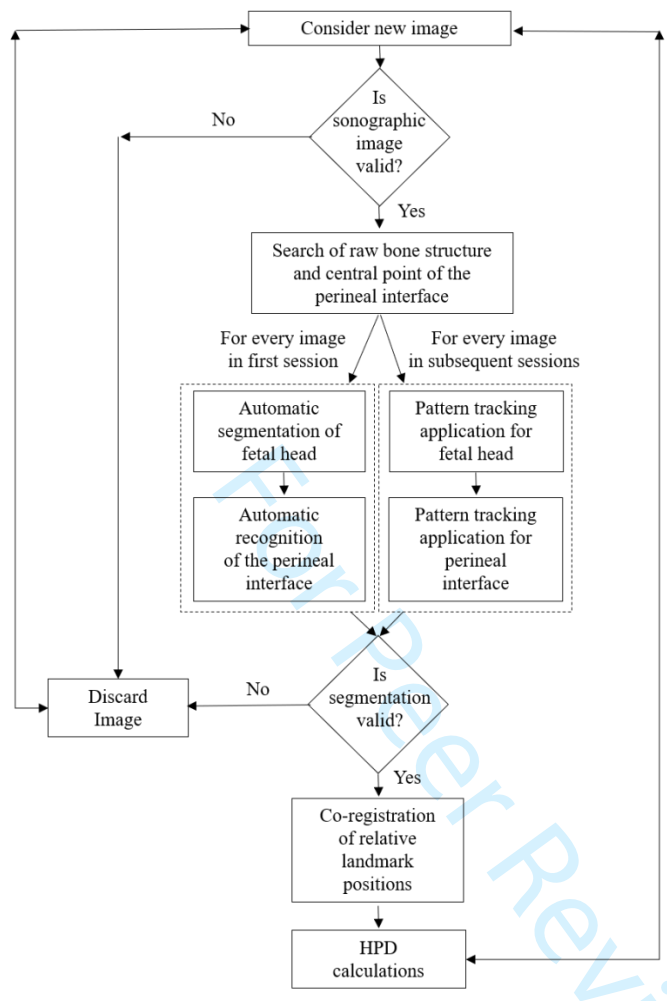


Fig. 2. Schematic representation of the adopted algorithm for HPD calculation.

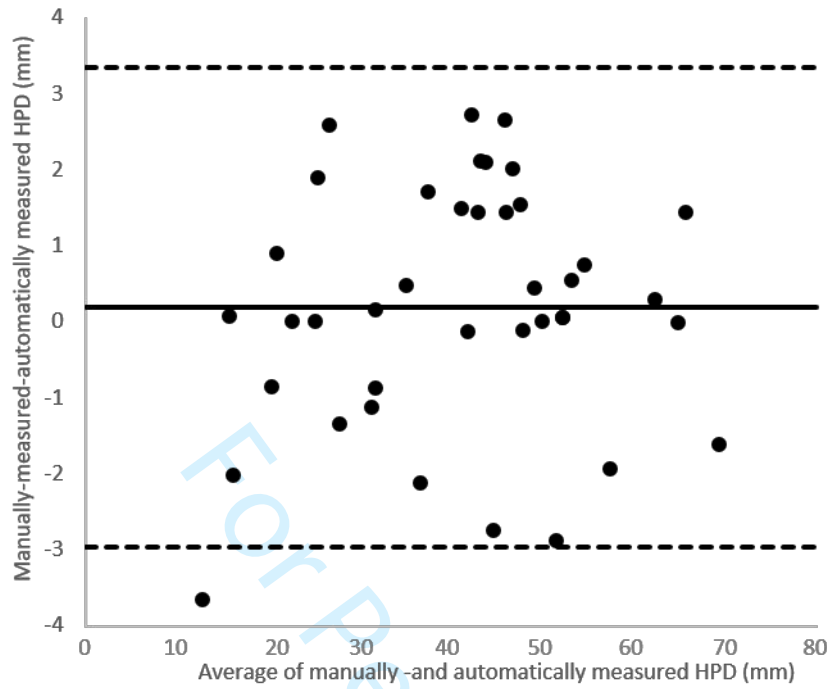


Fig. 3. Measurement agreement plot for the comparison of manually- and automatically-measured HPD values (dotted lines identify the 95% limits of agreement).

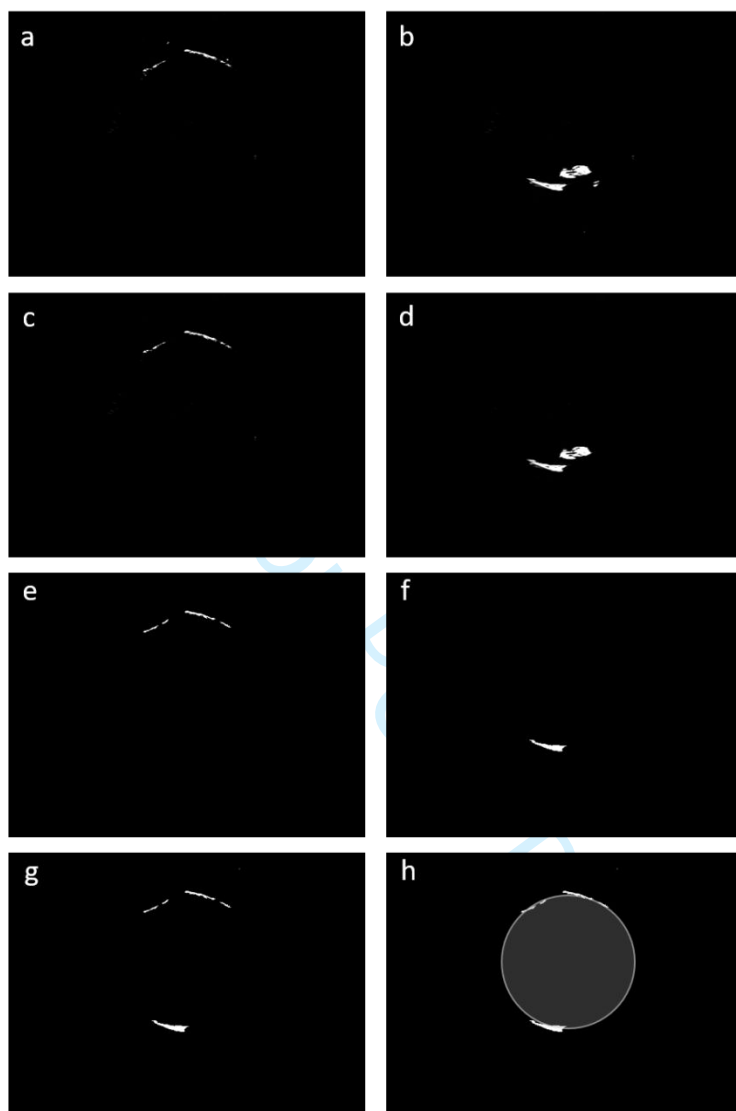


Fig. 4: Steps for the automatic identification of fetal head in a typical ultrasound image frame: (a,b) 'raw' identification of fetal head upper (a) and lower (b) edges, according to pixel position in the image and to their gray-level values, and conversion to a binary map; (c,d) median filter application and morphological evaluation on fetal head upper (c) and lower (d) edges; (e,f) hole-filling for fetal head upper (e) and lower (f) edges; (g) merging of fetal head structures; (h) determination of fetal head center and radius.

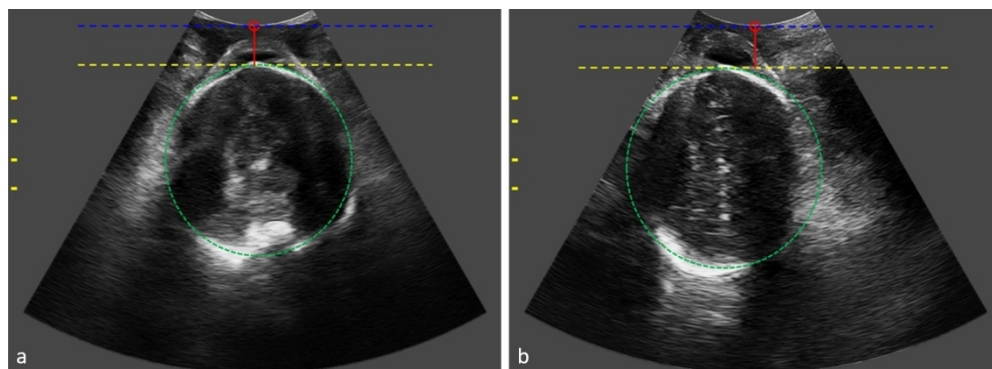
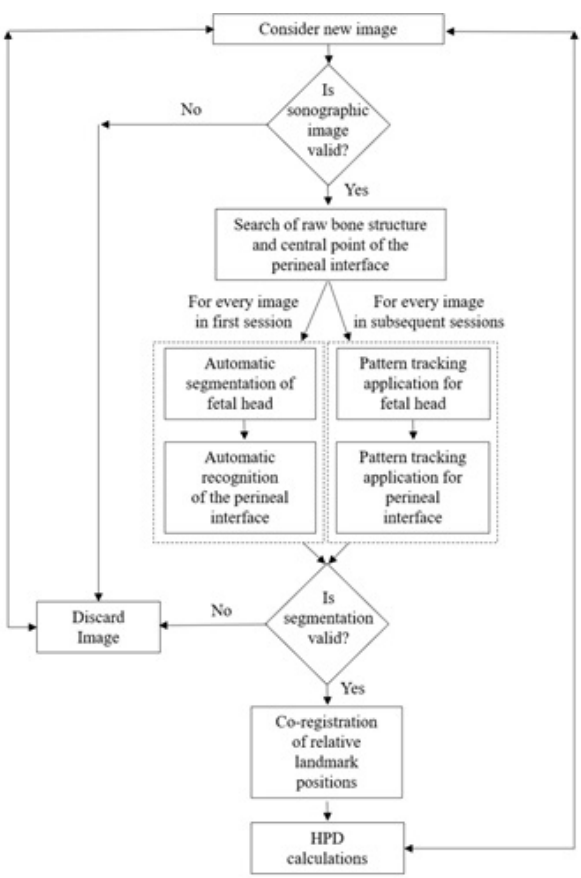


Fig. 1. a) Automatic segmentation of a typical ultrasound image acquired transperineally on the axial plane: the HPD value is identified by the length of the vertical segment between the dotted lines; b) Example of automatic image segmentation when the fetal head was not in the center of the ultrasound image

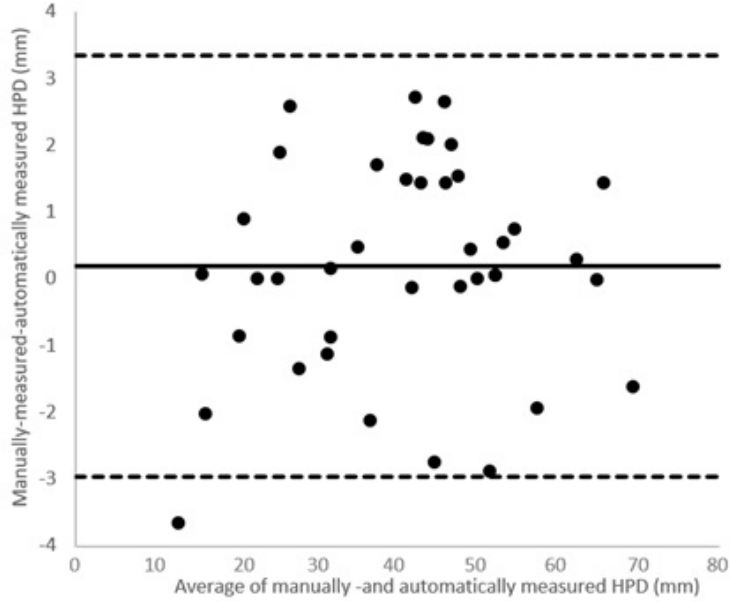
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Schematic representation of the adopted algorithm for HPD calculation

150x129mm (96 x 96 DPI)



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

150x129mm (96 x 96 DPI)

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<i>Difference between the two methods (mm)</i>									
			<i>95% CI</i>		<i>95%</i>				
<i>CC</i>	<i>mean</i>	<i>of mean</i>	<i>SD</i>	<i>lower limit</i>	<i>upper limit</i>	<i>lower limit</i>	<i>upper limit</i>	<i>CI of</i>	<i>Range</i>
			-0.33 to			-3.86 to -	2.45 to		-3.65 to
.994	.18	0.67	.16	2.98	.34	2.09	4.22		2.72

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