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1 **Probe motion during mid-trimester fetal anomaly scan in the clinical setting: a**  
2 **prospective observational study**

3  
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31

32 **Introduction**

33 This study aims to investigate probe motion during full mid-trimester anomaly scans.

34

35 **Methods**

36 We undertook a prospective, observational study of obstetric sonographers at a UK University  
37 Teaching Hospital. We collected prospectively full-length video recordings of routine second-  
38 trimester anomaly scans synchronized with probe trajectory tracking data during the scan.  
39 Videos were reviewed and trajectories analyzed using duration, path metrics (path length,  
40 velocity, acceleration, jerk, and volume) and angular metrics (spectral arc, angular area, angular  
41 velocity, angular acceleration, and angular jerk). These trajectories were then compared  
42 according to the participant level of expertise, fetal presentation, and patient BMI.

43

44 **Results**

45 A total of 17 anomaly scans were recorded. The average velocity of the probe was  $12.9 \pm 3.4$   
46 mm/s for the consultants versus  $24.6 \pm 5.7$  mm/s for the fellows ( $p=0.02$ ), the average  
47 acceleration  $170.4 \pm 26.3$  mm/s<sup>2</sup> versus  $328.9 \pm 62.7$  mm/s<sup>2</sup> ( $p=0.02$ ), and the average jerk  
48  $7491.7 \pm 1056.1$  mm/s<sup>3</sup> versus  $14944.1 \pm 3146.3$  mm/s<sup>3</sup> ( $p=0.02$ ), the working volume  $9.10^6$   
49  $\pm 4.10^6$  mm<sup>3</sup> versus  $29.10^6 \pm 11.10^6$  mm<sup>3</sup> ( $p=0.03$ ), respectively. The angular metrics were not  
50 significantly different according to the participant level of expertise, the fetal presentation, or  
51 to patients BMI.

52

53 **Conclusion**

54 Some differences in the probe path metrics (velocity, acceleration, jerk and working volume)  
55 were noticed according to operator's level.

56

57 **Keywords:** Fetal ultrasound; anomaly scans; probe trajectory; trajectory; metrics; obstetrics;  
58 pregnancy; screening.

59

60 **Introduction**

61

62         Ultrasound is a dynamic, real-time imaging modality widely used for pregnancy  
63 screening, but it can be challenging depending on operator's level, fetal presentation, and  
64 patient body mass index (BMI). In accordance with the latest International Society of  
65 Ultrasound in Obstetrics and Gynecology (ISUOG) guidelines, routine mid-trimester fetal  
66 ultrasound examination includes an evaluation of the following: cardiac activity, number of  
67 fetuses, fetal size, basic fetal anatomy including head, face, heart, abdomen, limbs (skeletal),  
68 umbilical cord, genitalia, placental appearance and location, and amniotic fluid volume [1].  
69 Although experienced sonographers usually follow a systematic approach, there is no universal  
70 scanning protocol at this time [2]. Hence, each sonographer may conduct the examination  
71 differently. In a previous study by Drukker et al., each anomaly scan was found to be unique in  
72 its scanning sequence with a wide variation during routine second-trimester anomaly scans [3].

73         However, in some studies conducted in simulated settings, similarities between the  
74 trajectories of experts were found, suggesting a relationship between expertise and trajectory  
75 [4,5]. For example, differences in trajectory metrics such as path length, velocity acceleration,  
76 or dimensionless squared jerk could discriminate expertise. These studies demonstrated a link  
77 between sonographers' hand motion and their expertise during simulation sessions.

78         Repeating this experiment in a clinical environment allows us to determine if the skills  
79 assessed in a simulated environment can be translated to clinical reality and how robust these  
80 skills are when presented with the variability inherent to obstetric scanning. Specifically, the  
81 degree to which fetal presentation and maternal body type impact the way the sonographers  
82 move the probe remains unknown. To our knowledge, no study quantifying probe motion  
83 during real-life ultrasound acquisition according to those specific conditions has been described  
84 so far. We hypothesized that trajectory metrics might differ according to operator's level, fetal  
85 presentation (e.g., cephalic or breech) or patient body mass index (BMI).

86         Therefore, this study aimed to quantitatively describe the probe trajectory during a  
87 routine mid-trimester ultrasound scan according to operator's level, fetal position and patients'  
88 BMI.

89

90 **Methods**

91 *Setting*

92 We undertook a prospective, observational study of sonographers at the Ultrasound  
93 Screening Unit of University College London Hospital NHS Foundation Trust, London, UK  
94 (UCLH).

95 Women attending the Ultrasound Screening Unit for a routine second-trimester anomaly  
96 scan on a Tuesday afternoon between February 1<sup>st</sup> and June 30<sup>th</sup> 2023 were offered the  
97 opportunity to participate in the study. Each sonographer, a senior ultrasound fellow working  
98 in that unit or a fetal medicine consultant was asked to conduct a routine second-trimester fetal  
99 ultrasound scan using a VolusonE8® ultrasound machine (GE Healthcare, Chicago, Illinois).  
100 Operators were allowed unlimited time to complete the scan, following the UK FASP  
101 guidelines [6] and international guidelines, which requires the scan of the following structures:  
102 head/brain, coronal face view (nose/lips), sagittal face (fetal profile), thorax, heart, abdomen,  
103 spine, kidneys, bladder, femur, limbs, placenta, amniotic fluid, and Doppler imaging of the  
104 maternal uterine artery [1]. The study was approved by the NHS Research Ethics Committee.  
105 Informed consent was obtained from each participant and patient.

106

107 *Acquisitions setting*

108 We prospectively collected full-length video recordings of routine second-trimester  
109 anomaly scans using the device's high-definition multimedia interface (HDMI) output; we  
110 recorded them using an AV.io HD® graphic board (Epiphan videos, USA) (**Figure 1a**). The  
111 probe's position was tracked using the Aurora® electromagnetic tracking system (NDI Inc.,  
112 Waterloo, Ontario, Canada), whose field generator was placed under the patient. To track the  
113 probe a 6 degrees-of-freedom (DOF) sensor was attached to the ultrasound probe by means of  
114 a custom 3-D printed holder (**Figure 1b**). The probe tracking frequency was 40 Hz. The data  
115 was synchronized, recorded, and gathered on an ODX® laptop using an in-house application  
116 developed in LabVIEW, National Instruments (TM) (**Figure 1c**).

117

118 *Motion data analyzing*

119 Trajectory analysis was performed on a dedicated computer using Intel® Xeon(R) W-  
120 2245 CPU @ 3.90GHz with 64Go RAM using Matlab\_R2018a. For each trajectory, the  
121 following metrics were calculated:

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- **Duration (D)** corresponds to the execution time of the second trimester scans from the starting image until the end of the scan. It is measured in minutes (min) using the video.

- **Path metrics:**

1. **Path Length (PL)** represents the total distance traveled by the probe during the execution of the task (mm).
2. **Average Velocity (AV)** corresponds to the average linear speed of the probe. mm/s.
3. **Average Acceleration (AA)** : acceleration of the probe during the task ( mm/s<sup>2</sup>).
4. **Average Jerk (AJ)** derivative of the acceleration, also known as “smoothness” measure (mm/s<sup>3</sup>).
5. **Working volume (WV)** represents the volume of the convex hull for each trajectory (mm<sup>3</sup>)

- **Angular metrics:**

6. **Angular area (AA)** is a size measurement for a region of possible directions from a point, which is equivalent to regions on the surface of a sphere (rad<sup>2</sup>).
7. **Angular spectral arc (SPARC)** quantifies movement intermittencies (angular smoothness) but is independent of its amplitude or duration (no unit).
8. **Angular Velocity (AV)** is the vector measure of the rotation rate, which refers to how fast an object rotates or revolves relative to another point. It is expressed in radians per second (rad/s).
9. **Angular Acceleration (AAcc)** is defined as the time rate of change of angular velocity (rad/s<sup>2</sup>).
10. **Angular Jerk (AJ)** is a derivation of angular acceleration (rad/s<sup>3</sup>).

149 All the metrics were compared according to the fetal presentation (i.e., cephalic or  
150 breech) and the patient BMI (i.e.,  $<25$  or  $\geq 25$ ).

151

#### 152 *Video analysis*

153 The videos were manually annotated using CapCut®. The image sequence and the  
154 image capture frequency were collected, as well as the starting image and finishing image. The  
155 percentage of completion of the scan according to current international guidelines was  
156 calculated (number of standard planes achieved/ number of standard planes required x100).  
157 The number of images saved per anatomic region (brain, face, heart, abdomen, skeletal, spine,  
158 genitalia, placenta, cord) was also collected.

#### 159 *Statistical analysis*

160 Qualitative variables are presented with numbers and percentages. Quantitative variables  
161 are expressed with mean  $\pm$  SD. Data were analyzed by conducting the Student's *t*-test or Mann–  
162 Whitney *U*-test depending on the distribution Gaussianity. Qualitative data associations were  
163 analyzed using a chi-squared test or Fisher's exact test. Statistical analyses were performed using R  
164 via BiostaTGV (<https://biostatgv.sentiweb.fr/>).

165 **Results**

166 **Demographics**

167 A total of 17 scans were recorded. Sonographers' and patients' demographics are  
168 presented in **Table 1**. Mean gestational age at scanning was  $20.4 \pm 0.7$  for the fellows and  
169  $19.6 \pm 1.5$  for the consultants.

170

171 **Probe Motion data: trajectory and angular metrics.**

172 Firstly, the path metrics were different according to the level of the participant  
173 (consultant or fellow), except for the mean path length of the probe trajectory which did not  
174 reach significance ( $16.6 \pm 4.9\text{m}$  for consultants versus  $27.5 \pm 15.4\text{m}$  for the fellows,  $p=0.18$ ). The  
175 other path metrics were all significantly different according to the level of the participant (**Table**  
176 **2**).

177 Secondly, the angular metrics were not different according to the participant's level  
178 of expertise (**Table 2**), to the fetal presentation (cephalic or breech) (**Table 3**) nor to the  
179 patient's BMI (**Table 4**).

180

181 **Video Data**

182 The mean number of images captured was  $61.8 \pm 23.9$ . The image capture frequency was  
183  $3.8 \pm 1.6$  per minute. The starting area was the heart for 14 patients (82.3%), or the head for 2  
184 patients (11.7%). The ending image was most frequently the uterine arteries for 3 patients  
185 (17.6%), fetal annexes for 4 patients (23.5%) (cord, amniotic fluid, placenta), or the profile for  
186 2 patients (11.7%). The mean number of images saved for fellows  $75 \pm 22$  was and the mean  
187 number for consultants was  $40 \pm 3$ . The mean number of images needed to complete the heart  
188 examination was  $18.3 \pm 10.3$ ,  $7.1 \pm 5.1$  for the spine, and  $3.8 \pm 1.6$  for the brain ( $p < 0.01$ ). The  
189 comparison of the volume of images saved according to fetal presentation is presented in **Table**  
190 **5**. The total number of images captured was significantly higher for breech presentation, as  
191 well as the number of images captured to secure the heart examination in this presentation.

192

193 **Discussion**

194

195 *Main Findings*

196 There was a high heterogeneity in the number of captured images (between 32 and 100),  
197 sequence, and path metrics: path length of the probe (from 11 m to 60 m), with consultants  
198 being shorter (18.5 min versus 21.3 min), slower (12.9 mm/s versus 24.6 mm/s), and smoother  
199 (jerk about 7500 versus 15000) than fellows.

200 However, angular metrics were similar among sonographers, meaning that the rotation  
201 of the probe was very homogenous among sonographers even under different clinical conditions  
202 such as different BMIs or fetal positions. Angular acceleration, velocity and jerk were similar  
203 across the different groups.

204 The breech position seems to be most challenging, with significantly more images  
205 captured compared to the cephalic presentation (72±15 versus 43±21, p=0.01) and requiring on  
206 average one additional minute of scan time (19.8 min versus 18.9 min, p=0.10). No significant  
207 differences appeared comparing BMI above or below 25.

208

209 *Comparison with existent literature*

210 Most of the studies analyzing motion data during scans were performed in a simulated  
211 setting which allows automatic recording of probe trajectories during training and evaluation.  
212 However, findings from simulation training settings need to be verified in clinical settings.  
213 First, the total path length of an anomaly second-trimester scan was between 11m and 60m, as  
214 compared to simulated exercises of around 1m to 2m, which was a much longer task [4,5].  
215 Considering the working volumes, they were also larger in the clinical setting (around 16.10<sup>6</sup>  
216 mm<sup>3</sup> than in the simulated settings (around 1.10<sup>6</sup> mm<sup>3</sup>), probably due to the more limited  
217 simulated tasks and the reduced number of degrees of freedom of the simulator probe. Second,  
218 the average velocity of the probe in the present study was 24.6 mm/s for the fellows versus 12.9  
219 mm/s for the consultants (p=0.02). In the simulated setting, it was the opposite : experienced  
220 sonographers were faster (around 29 mm/s) than novices (around 19mm/s), meaning that the  
221 experienced sonographers move the probe slower and more accurate on a real patient,  
222 examining a real baby, compared to completing a task on a simulator [5]. Similarly, the  
223 acceleration was lower in consultants (170.4 mm/s<sup>2</sup>) than fellows (328.9 mm/s<sup>2</sup>) on real patients  
224 (p=0.02), as compared to the simulated setting : 228 mm/s<sup>2</sup> for the experts versus 137mm/s<sup>2</sup> for  
225 the novices[5]. Considering the jerk, it was much higher in the clinical setting (around 12000  
226 mm/s<sup>3</sup>) versus during simulated exercises (around 4528 mm/s<sup>3</sup>) for everybody. However,

227 considering the metrics by a whole, they were of the same order of magnitude in both the  
228 simulated and clinical settings.

229 The angular metrics are a handy tool for representing rotations in space. Adjusting the  
230 probe rotation, and therefore the view, is a major skill in fetal ultrasound, allowing the operator  
231 to obtain sagittal views starting from a transversal one. Indeed, the transversal views are easily  
232 obtained solely by translating the probe from the maternal pubic bone (head circumference) to  
233 the abdomen and femur in a cephalic presentation, adding very small inclinations or rotations  
234 to adapt. The sagittal views (fetal profile, spine, corpus callosum) are the most challenging to  
235 obtain, with lateral translations on maternal sides, rotations, and extreme inclinations of the  
236 probe often needed. We hypothesized that some differences in the rotation of the probe would  
237 appear according to fetal presentations por the level of the participants. However, this was not  
238 the case here, with very similar angular metrics all across the cases, meaning that, the manner  
239 in which the probe is rotated was relatively constant, even in different difficulty levels such as  
240 different fetal positions or augmented BMI in patients.

241 The manner of conducting the scans may also differ slightly according to the patient  
242 BMI. It has been found that maternal obesity increases the rate of suboptimal visualization for  
243 the fetal cardiac structures by 49.8% and for the craniospinal structures by 31% [10]. In the  
244 present study, we found no differences in the trajectory nor rotation metrics using a BMI  
245 threshold of 25, although the working volume seemed to be higher for higher BMI ( $p=0.06$ ).  
246 More difficulties and therefore differences may arise for more extreme BMIs. Maybe a cut-off  
247 of 30 would have been more relevant.

248

### 249 *Strengths and Limitations*

250 The main strength of this study is the prospective collection of synchronized video data  
251 and trajectory metrics in the real clinical setting of a university teaching hospital. This is  
252 reflective of real life compared to our previous studies in simulated settings [4,6]. Real patients  
253 are more challenging than simulators because of changing conditions of the examinations (e.g.,  
254 higher BMIs, moving fetuses, different fetal presentations).

255 One limitation of this study is the low number of participants, which was limited by the  
256 rooms' occupation, the study's acceptability for both fellows and patients and their availability.  
257 Performing a scan in front of stressed patients is very challenging and the stakes are so high  
258 that operators are not always keen to add research challenges on top of it. Another limit is that  
259 we did not record the communication or interactions with the patient, which could be interesting  
260 to highlight how it affects the workflow of the sonographer and the sequence of images[9]. For

261 example, some couples may ask to see the face again or the sex of the baby in the middle of the  
262 scan. A further limitation of this study was that the tracking was not perfect; in some  
263 acquisitions, the pose metrics were not correctly tracked, and there was some intermittent  
264 tracking loss. The participants for whom there was more than 30% tracking loss were therefore  
265 excluded from the analysis, mostly for trajectory metrics. Despite this, our dataset of trajectories  
266 and ultrasound videos is the first dataset of this type, and it reflects the reality of ultrasound  
267 screening units in various clinical conditions.

268

### 269 *Implications-Interpretation*

270 This study emphasized the skills needed by a sonographer, able to capture a mean of 61  
271 images per patient with a mean duration of 18 minutes, representing a workflow of 3 to 4 images  
272 per minute, while moving the hand at a velocity of 11 mm/s. It also requires coordinating a  
273 discussion with the patient and sometimes the partner, the correct interpretation of the images  
274 and, at the same time, remembering the checklist of 35 structures and 21 images needed for  
275 mid-trimester scans according to the ISUOG [1]. In a study about fetal ultrasound guidance,  
276 Droste et al. were able to predict the next movement that an expert sonographer would perform,  
277 confirming that the way to conduct fetal ultrasound is predictable in experts [7]. However, the  
278 way to move the probe and rotate it to obtain the correct planes is challenging to teach and leads  
279 to long learning curves [8], [9]. Although it is now possible to model the trajectory of the probe  
280 held in the operator's hands to approach the ideal trajectory, we are still a long way from  
281 standardized practice, a single ideal movement, an ultrasound applicable to all clinical  
282 situations, which a robot could perform.

283 Secondly, our findings reveal that the heart seemed to be the most challenging  
284 structure to examine for sonographers. A mean of 18 images of the heart was captured per scan  
285 and per patient when 5 only are minimally required in the international guidelines: heart  
286 activity, 4 chamber view, right outflow tract, left outflow tract, and three vessel view [1]. The  
287 fetal heart is a fast-moving structure in a moving fetus, in which the possibility of more than  
288 one hundred conditions can be detected, most of them life-threatening [12]: [13]. This may  
289 explain why so many images were saved for this organ. The sonographers were willing to secure  
290 the heart examination, looking for the best planes and repeating them, especially for trickier  
291 fetal positions like breech. The other challenging structure was the spine, with a mean of 7  
292 images captured per scan. This can be explained by the fact that sagittal planes are more difficult  
293 to obtain, and the spine is a long and moving structure that cannot verify its integrity with a

294 single image. The international recommendations mention that the scan should include  
295 transversal and sagittal spine views without further details [1]. The brain, interestingly,  
296 appeared to be easily investigated at first glance when normal with a mean of 3 to 4 images  
297 only. After the heart activity was checked, it was generally the first structure to be analyzed.  
298 The total number of images needed to finalize the scan was 2 to 3 times higher than the essential  
299 number according to the ISUOG protocol. This can be explained by higher expectations and  
300 requirements in a university centers, and by the fellows' wish to make their fetal examination  
301 absolutely safe. However, we should advise the trainees to take their time to get each plane  
302 correct rather than taking a lot of uncorrect planes. Also, we should advise them to use the  
303 systematic head-to-toe approach, which was used by the consultants in our study, to reach a  
304 more standardized way of scanning.

305         The increasing number of images required in new guidelines, 21 in the ISUOG  
306 standards, makes it more difficult to remind the checklist and makes an omission more probable.  
307 Technologies such as scan assistants that automatically assess the completion of a scan could  
308 offer a solution to address this issue [11].

309

### 310 **Conclusion**

311         In a clinical setting, some differences in the path metrics (velocity, acceleration, jerk  
312 and working volume) were noticed according to participant level. However, angular metrics,  
313 i.e., the quantity of rotation applied to the probe, were not affected by operator's level, fetal  
314 presentations nor patient's BMI.

315

316

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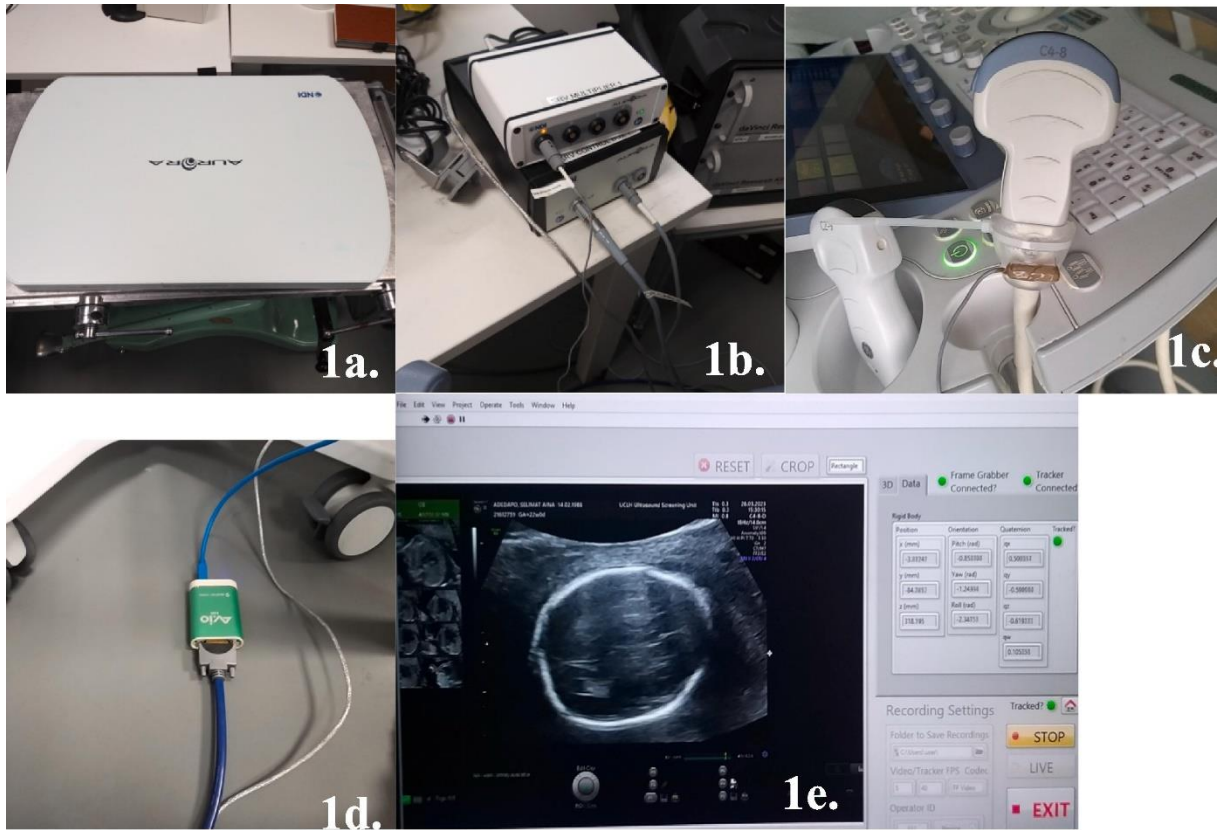


Fig. 1. The probe's position was tracked using the Aurora® electromagnetic tracking system (NDI Inc., Ontario, Canada), which table was placed under the patient (a-b). To track the probe a 6 degree-of-freedom (DOF) sensor was attached to the ultrasound probe by means of a custom 3-D printed holder (c). To record the video, an [AV.io HD®](#), Epiphan videos, USA was used (d). The data were synchronized and recorded using the Scanview Data Recorder software® (e).

**Table 1.** Participant demographics.

<b>Sonographers' background</b>	<b>N=17</b>	<b>Patients' demographics</b>	<b>N=17</b>
<b>Age</b> Mean±SD	38±5.6	<b>Age</b> Mean±SD	35.7±6.5
<b>Years of experience</b> Mean±SD Less than 5 years N (%) More than 5 years N (%)	6±5.6 14 3	<b>Gestational Age</b> Mean±SD	20.4±1.7
<b>Background</b> N (%) OB/GYN Midwife Radiologist	13 3 1	<b>BMI</b> Mean±SD <25 ≥25	26.9±6.3 10 7
Ultrasound senior fellows Fetal medicine Consultants	14 3	<b>Fetal Presentation</b> Cephalic Breech	7 10

**Table 2.** Number of images captured per anatomic region according to the fetal presentation (breech or cephalic).

	<b>Breech N=10</b>	<b>Cephalic N=7</b>	<b>p</b>
% completion of the scan	98.8%±3.17	95.8%±9.3	0.71
Total number of images captured	72±15	43±21	<b>0.01</b>
<b>Number of images per anatomical region</b>			
Brain images	4±3	3±1	0.39
Face	6.6±4.0	4.8±2.3	0.39
Heart	23±9	12±8	<b>0.04</b>
Spine	7±6	5±2	0.46
Abdomen circumference	1.2±0.7	1.4±0.5	0.33
Genitalia	1.6±1.4	1.8±1.4	0.23
Skeletal (except spine)	9.8±3.7	9.0±3.1	0.46
Placenta	0.8±0.6	1.25±0.4	0.36
Umbilical cord	1.5±1.1	1.6±0.8	1