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# Development of an Innovative Surgical Navigation System for Sacrospinous Fixation in Pelvic Surgery

Julie Rozaire, Alexandre Naaim, Laura Dubuis, Gery Lamblin

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1 **Development of an innovative surgical navigation system for sacrospinous fixation**  
2 **in pelvic surgery**

3

4 Julie Rozaire (Research engineer)<sup>a</sup>, Alexandre Naaim (Research engineer, Ph.D)<sup>a</sup>, Laura  
5 Dubuis (Research engineer, Ph.D)<sup>a</sup>, Gery Lamblin (M.D, Ph.D)<sup>a,b</sup>

6

7 <sup>a</sup> Univ Lyon, Univ Gustave Eiffel, Université Claude Bernard Lyon 1, LBMC UMR\_T9406,  
8 F69622, Lyon, France

9

10 <sup>b</sup> Hôpital Femme Mère Enfant, Service de Chirurgie Urogynécologique, Hospices Civils  
11 de Lyon, Bron, France

12

13 **Corresponding Author:** Gery Lamblin

14 Address of corresponding author:

15 Service de Chirurgie Urogynécologique, Hôpital Femme Mère Enfant, Hospices Civils de  
16 Lyon, 59 Boulevard Pinel, 69677 Bron, France.

17 Telephone number: + 33-4-72-35-58-86 / +33-6-61-58-21-93

18 Fax number: +33-4-27-86-92-67

19 E-mail address: gery.lamblin@chu-lyon.fr

20

21 **Names of co-authors:**

22 Julie Rozaire<sup>a</sup>, Alexandre Naaim<sup>a</sup>, Laura Dubuis<sup>a</sup>

23

24 **Adresse of co-authors:**

25 Laboratoire de Biomécanique et de Mécanique des Chocs, 25 avenue François  
26 Mitterrand, case 24, 69 675 Bron Cedex, France

27

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35 Manuscript writing.

36 Alexandre Naaim: Protocol/Project development, Data collection, Manuscript  
37 correction.

38 Laura Dubuis: Protocol/Project development, Investigator, Supervisor.

39 Gery Lamblin: Protocol/Project development, Investigator, Supervisor.

40

41 **Precis**

42 A new navigation method for sacrospinous fixation based on motion capture  
43 technology proved to be accurate and effective under the surgery-like conditions of  
44 our study.

45

46

47 **Abstract**

48 **Study Objective.** To validate the use of an innovative navigation method for  
49 sacrospinous fixation in surgery-like conditions as a new teaching tool and surgical  
50 method.

51 **Design.** 2-month-experiment prospective pilot study between July and August 2021.

52 **Setting.** Biomechanics laboratory academic research.

53 **Population.** 29 participants: 9 gynecological surgeons and 20 participants with no  
54 medical background.

55 **Measurement and Main Results.** The experiment was composed of two training  
56 phases dedicated to improve the hand-eye coordination and suture skills on a  
57 training mock-up, and of a suturing phase on a pelvic mock-up designed to recreate  
58 the surgery-like conditions of a sacrospinous fixation. The surgeons provided  
59 qualitative feedback on the bio-accuracy of the mock-ups and evaluated the  
60 ease-of-use of the navigation software. Non-surgeons were included to assess  
61 the progression of the suture performance between two experiments performed  
62 one week apart (Session 1 & 2). The main objective for participants was to reach a  
63 virtual target and to stitch sacrospinous ligaments. For Session 1, an overall comfort  
64 score of 7.2/10 was attributed to the tool; 14 (42%) surgeon suture attempts and  
65 63 (65%) non-surgeon suture attempts were accurate (i.e. below the 5-mm  
66 threshold). 22 (67%) surgeon suture attempts and 28 (34%) non-surgeon suture  
67 attempts were fast (i.e. in the first two quantiles of the duration dataset). An  
68 improvement of the non-surgeon performance was observed between the two  
69 sessions in terms of duration (Session 1:  $46\pm 20$  sec; Session 2:  $37\pm 18$  sec;  
70  $p=0.047$ ) and distance (Session 1:  $3.8\pm 1.3$  mm; Session 2:  $3.2\pm 1.4$  mm;  $p=10^{-5}$ )  
71 for the last suturing exercise.

72 **Conclusion.** This new motion-capture-based navigation method for sacrospinous  
73 fixation tested under surgery-like conditions seemed to be accurate and effective.  
74 The next step will be to design a pelvis model more adapted to the constraints  
75 of a sacrospinous fixation and to validate the benefits of this method compared  
76 to current techniques.

77 **Keywords:** Computer-assisted surgery; Pelvic organ prolapse; Pelvic floor disorders;  
78 Sacrospinous fixation; Surgical training.

79 **Introduction**

80 Improving the treatment of genital prolapse will constitute a major challenge of the  
81 coming years in gynecology. Indeed, the lifetime risk of undergoing a procedure for  
82 prolapse is 11.1%, and revision surgery is required in 29.2% of cases [1, 2].  
83 Moreover, as the Western population ages, the demand for care related to these  
84 pelvic disorders is expected to significantly grow within the next decades [3].  
85 Sacrospinous ligament fixation and uterosacral ligament suspension both are options for  
86 anterior and apical vaginal vault suspension treatment [4-7]. However, since it is a  
87 vaginal surgery, surgeons have a limited visual access to the sacrospinous ligament  
88 and use palpation to localize the ischial spine mark and achieve an accurate fixation.  
89 Many other surgical procedures already benefit from guidance assistance to gain  
90 visibility while remaining minimally invasive [8, 9]. The integration of such navigation  
91 technologies in the daily practice remains to be achieved.

92 Indeed, training models constitute useful formation tools [10]. From low-cost creative  
93 solutions to cutting-edge virtual reality simulators, they were designed to enhance  
94 hand-eye coordination [11-13]. Despite the success of navigation methods and the  
95 rise of simulators, sacrospinous fixation is still performed with a limited visual  
96 control on the ligament after a delicate learning process. Our study aimed to  
97 evaluate the accuracy and rapidity of the proof-of-concept of an innovative  
98 navigation method and its training model applied to sacrospinous fixation in  
99 vaginal prolapse repair. The objective of future studies will be to use this  
100 navigation method to develop a teaching method and then to implement this  
101 technology in the operating room.

102

103 **Material and Method**

104 **Population**

105 Two separate groups were evaluated on this navigation method to perform  
106 sacrospinous fixation. The first group was composed of gynecological surgeons in  
107 training and was dedicated to provide qualitative feedback on the use of the  
108 navigation method and on the mock-up accuracy. The second group gathered  
109 participants with no medical background and all equally inexperienced in surgical  
110 navigation, to allow the study of the progression of the suture performance between  
111 two runs of the experiment. Participants from both groups were healthy and active.

112 All participants were registered to the French social security system. Surgeons were  
113 recruited within the *Hôpital Femme Mère Enfant (Hospices Civils de Lyon, Bron,*  
114 *France)* and non-surgeons were recruited from the *Laboratoire de Biomécanique et*  
115 *Mécanique des Chocs (Université Claude Bernard Lyon 1, LBMC, Bron, France).*

### 116 **Suturing device**

117 Among the different suturing devices available on the market, the CAPIO™ SLM  
118 (Boston Scientific®, Boston, US) was selected (Fig. 1). This suturing device was  
119 relevant for our navigation method because a rigid tool is needed to infer the  
120 position of the suture needle from the position of the suturing device body. It was  
121 furnished with polypropylene suturing needles for CAPIO (Boston Scientific®,  
122 Boston, US). Its use is simple: a pressure on the piston allows the hook on which  
123 the needle is fixed to be released. The needle then hits a suture catcher, which  
124 holds the thread in place.

125

### 126 **Navigation**

127 The navigation method relied on motion capture technology using optoelectronics  
128 cameras. These infrared cameras can track the 3D position of reflective markers,  
129 allowing to follow the rigid body motion of clusters of markers fixed to different  
130 objects.

131 In this study, the followed objects were the suturing device, the piston of the suturing  
132 device, and the 2 pelvis mock-ups (Fig. 2). Ten optoelectronic cameras Miquis M3  
133 (Qualisys®, Gothenburg, Sweden) were used at a frequency of 100 Hz. The tracking  
134 of the rigid body in real time was performed using Qualisys Track Manager  
135 (Qualisys®, Gothenburg, Sweden), which allowed to send in real time the position  
136 and orientation of the object to the Unity software (Unity Technologies®, San  
137 Francisco, US).

138 The visual assistance at the disposal of participants was a visualization software that  
139 was developed with the cross-platform game engine unity. Connected with Qualisys  
140 Track Manager, it uses the real time position of rigid bodies and displays their  
141 movement in space. Participants had access to the position of the suturing device  
142 (Fig. 3b) relative to the position of the mock-ups (see next section Mock-ups).

143 Digitized geometries displayed by the visualization software represented the physical  
144 objects of the experiment (suturing device, mockups) as virtual navigation guides.  
145 They were conceived using the software Fusion 360 (Autodesk®, San Rafael, US).

146 The pelvis structure (Fig. 3b) was designed using the segmentation of a MRI (magnetic  
147 resonance imaging) scan obtained with the consent of a control patient.

148 We chose to divide the screen between three 2D views (showing the front, the side,  
149 and the top of the mock-up), one subjective view (as if a camera was on the hook of  
150 the suturing device), and two close-up views on the side and below the suturing  
151 device (Fig. 3a).

152 Several navigation aids were available in our software to guide the participants during  
153 the experiment. A line linked the target to the reference point on the suturing device,  
154 the color of the suturing device (Fig. 3b) rod changed according to the distance to the  
155 target, thanks to a proximity indicator becoming green once the target was reached.  
156 Virtual red zones (Fig. 3b) materialized on the screen dangerous areas such as the  
157 highly vascularized and supplied with nerves areas, behind the ligaments and near  
158 the ischial spines. Performance information, such as the distance between the target  
159 and the suture catcher of the suturing device (in cm), the time spent in red zones  
160 (in s), and the duration of the attempt (in s) were indicated at the bottom right of the  
161 screen (Fig. 3). These information were frozen when the participants pressed the  
162 piston.

### 163 **Mock-ups**

164 Hand-eye coordination while looking at a screen requires training. Hence, in addition  
165 to a pelvis mock-up modeling the surgical conditions of the procedure, a training  
166 mock-up was designed as well (Fig. 2).

167 **Training mock-up.** The training mock-up consisted in a low-cost modular wood box  
168 inclined to recreate the angulation of the pelvis during the sacrospinous fixation  
169 procedure. It was designed to offer various environments and obstacles, virtual  
170 and real, to develop participant skills and to familiarize them with the different  
171 navigational aids.

172 **Pelvis mock-up.** This mock-up was designed to recreate the conditions of a  
173 sacrospinous fixation procedure. The 3D-printed pelvic structure was based on the  
174 same MRI segmentation as its screen display but was adapted to ease the mock-up  
175 conception. Two 4-mm thick sacrospinous ligaments were molded in silicone paste  
176 (Esprit Composite®, Paris, France) according to the segmented 3D image of the  
177 pelvis. They were inserted between the ischial spine and the coccyx so they could  
178 be replaced regularly, since they were perforated by the successive attempts of  
179 participants (Fig. 2). A 2-mm thick skin molded with rubber and silicone (SoloPlast®,

180 Fontanil-Cornillon, France) covered half of the bone structure on the perineum side.  
181 The vaginal hyatus was modelled by a slot on the silicone skin and a bladder balloon  
182 was used to fill the cavity modelling the organs. The pelvis mock-up was placed on an  
183 adjustable stand to set the pelvis in a position reproducing the conditions of the  
184 surgical procedure (Fig. 1).

## 185 **Protocol**

186 To study the participants' acceptance of the tool, as well as its accuracy and  
187 efficiency, both groups participated in a first experimental session (Session 1). A  
188 week later, the non-surgeon participants performed the experiment for a second  
189 time to analyze the learning effect (Session 2). The objective during each  
190 experiment was to stitch on virtual targets in different environments using only the  
191 visual assistance: the participants could look at either the screen or directly the  
192 mock-ups when they were not hidden. Targets only appeared on the screen where  
193 the position of both the mock-ups and the suturing device was displayed in real time.  
194 The experiment was divided into three phases composed of several exercises: a  
195 pointing and a suture training on the training mock-up, and a suturing phase on  
196 the pelvis mock-up. For each attempt, all participants began in a neutral  
197 position. The attempt started when the operator said "go" and ended when the  
198 participant pressed the piston of the suturing device. The "go" signal allowed  
199 participants to move from their neutral position and to enter the suturing device  
200 (and only the suturing device) in the mock-ups. At the end of each exercise,  
201 participants were asked which views and navigational aids were useful to help  
202 them reach the target.

203 **Pre-experiment.** Before the first session, participants were asked to fill in forms with  
204 details on their occupation, age, right or left handedness, and experience with  
205 sacrospinous fixation or motion capture navigation.

206 **Pointing and suture training phases.** The training mock-up was not hidden from  
207 the participants, but the increasing difficulty of the exercises encouraged them to  
208 focus only on the screen. For the two training phases, participants were allowed to  
209 repeat each exercise as many times as they wanted. Each training phase was  
210 composed of 3 exercises during which participants were asked to point and stitch a  
211 virtual target inside the training mock-up. Since there was no ligament for the pointing  
212 phase, the suture was performed on air, without support. Then, the mock-up was  
213 furnished with a silicone ligament and the suturing device was equipped with a needle



214 for the suturing phase. A silicone membrane was placed over the opening and a slot  
215 modeled the vaginal incision. The virtual target was set by pointing on the surface of  
216 a silicone ligament. Each time the stitch was placed on the ligament, the attempt was  
217 labeled as “success”. If the needle thread did not pierce the ligament, the attempt was  
218 labeled as “failure”. Before the first attempt and every two failures, participants were  
219 invited to feel the haptic feedback force between the suturing device and the silicone  
220 ligament once the ligament was phished with the suturing device. At each attempt,  
221 the distance to the target when the piston was pressed, the duration of the attempt,  
222 and the time spent in the red zones were recorded.

223 **Suturing phase.** Once the training phase was completed, participants began the  
224 suturing phase, during which they performed two suture exercises (suture exercise 1  
225 and suture exercise 2). For each exercise, participants were asked to suture both  
226 silicone ligaments (left and right) of the pelvis mock-up (Fig. 2). Participants were  
227 allowed to use the visual aids displayed on the screen but not palpation, and they  
228 were aiming at virtual targets set beforehand on each of the silicone ligaments (Fig.  
229 6) 2 cm from the ischial spines in order to minimize the risk of complication [15].  
230 During this phase, the pelvis mock-up was hidden from the participants by a curtain.  
231 For each of these 4 sutures, they could perform as many attempts as required to  
232 meet a “success”, and once they did meet a “success”, they were not allowed to  
233 attempt anymore, even if the result was not satisfactory to them. Before the first  
234 attempt on each side, participants were invited to feel the haptic feedback force of  
235 the suturing device once the ligament was phished while the skin of the mock-up  
236 was removed. Every two failures, participants were invited to feel the haptic  
237 feedback force again, but this time with the skin on.

238 **Post- experiment.** Finally, participants were asked at the end of each session to rate  
239 from 1 to 10 their comfort using the suturing device, the readability, and the ease of  
240 use of the display. Additionally, they were asked whether, in their opinion, the  
241 information on the screen were relevant and precise. Moreover, surgeons were asked  
242 if the pelvis mock-up modeled well enough the constraints and difficulties  
243 encountered during a sacrospinous fixation procedure.

244 **Data treatment.** Considering the width of the silicone ligament at the target position  
245 (15 mm), the precision objective was set to 5 mm to leave a reasonable safety  
246 margin before reaching the edges. By the end of the experiment, the dataset of  
247 durations of all successful suture attempts was divided into quantiles. Then,

248 successful suture attempts were plotted on a distance-duration diagram. They  
249 were split between “accurate” ( $\leq 5$  mm) and “inaccurate” ( $> 5$  mm) successful  
250 attempts on the distance axis, and between “fast” (in the first two quantiles of  
251 duration) and “slow” (in the last two quantiles of duration) on the duration axis.

252 **Statistical analysis.** Quantitative variables were expressed as median (range) or  
253 mean  $\pm$  standard deviation, and qualitative data as count (percentage). Statistical  
254 analyzes were performed using Python and Pandas. Comparisons between  
255 Session 1 and Session 2 values were performed using the Student t-test. A p-  
256 value  $< 0.05$  was considered statistically significant.

257 **Results**

258 The experimental phases of the study lasted two months, 9 surgeons from different  
259 medical background and 20 non-surgeons participated in the study. The age was 28  
260 (26-44) years for surgeons and 23 (19-30) years for non-surgeons (Table 1).

261 **Session 1**

262 One surgeon was excluded from the suturing phase due to a dysfunction of the  
263 software. The overall mean comfort score was 7.2/10, it was 8.2/10 for surgeons  
264 and 6.8/10 for non-surgeons ( $p=0.056$ ; Fig. 4). The overall mean readability score  
265 was 8.8/10 and the overall mean ease-of-use score was 8.1/10 (Fig. 4). Information  
266 were considered as relevant and precise enough for 100% of the participants.  
267 During the training phases, surgeons asked to perform more attempts than non-  
268 surgeons did: 4 attempts were needed for surgeons and 3 for non-surgeons to  
269 handle each exercise. By the end of the suturing phase (i.e., second suture  
270 exercise), participants managed to reach a precision of  $4.0 \pm 1.8$  mm within  $41 \pm 20$   
271 sec (Tables 2 and 3). The average failure rate per participant was 32% of attempts  
272 during the suture training phase and of 33% during the suturing phase.

273 **Session 2**

274 Only the non-surgeons participated in the Session 2. Most of their parameters  
275 improved. Their mean comfort score improved from 6.8/10 (Session 1) to 8.2/10  
276 (Session 2), matching the score of the surgeon group (Session 1).

277 Overall, during the suturing phase, participants improved the distance of the  
278 suture by 21% compared to Session 1. By the end of the suturing phase (i.e.,  
279 second suture exercise, Session 2) they reached a distance to the target of  $3.2$   
280  $\pm 1.4$  mm (Table 2). In addition, the speed also improved (by 15%) during the  
281 Session 2 compared to the Session 1, and participants reached by the end of  
282 the suturing phase (i.e., second suture exercise, Session 2) a duration of  
283  $37 \pm 18$  sec, compared to  $46 \pm 20$  sec for Session 1 (Table 3).

284 On average, 2 attempts were required per participant compared to 3 during  
285 Session 1. Moreover, in Session 2 and compared to Session 1, the failure rate of  
286 the suture training phase decreased by 21%, but the failure rate of the suturing  
287 phase decreased by 2%. The number of attempts reaching red zones was similar  
288 between both sessions, but the mean duration spent in these zones decreased by  
289 51% during Session 2.

290

291 **Distance and duration of successful attempts**

292 During the suturing phase of the Session 1, 22 (67%) attempts from surgeons were  
293 considered as fast, whereas 28 (34%) attempts from non-surgeons were.  
294 However, 53 (65%) non-surgeon attempts were accurate whereas 14 (42%)  
295 surgeon attempts were. Considering the suturing phase of the Session 2, 65 (81%)  
296 non-surgeon attempts were accurate and 48 (60%) were fast (Fig. 5).

297 **Discussion**

298 Surgical navigation system has constituted a major research issue for the  
299 improvement of procedures in many surgical fields [15]. Over the last five years,  
300 many authors have developed surgical navigation systems, especially in  
301 orthopedics [16-20] and neurosurgery [21-24]. Some authors have worked on the  
302 benefits of virtual reality for laparoscopic liver surgery and rectal surgery [25, 26].  
303 Although technologies might differ, one purpose remains: to improve the accuracy  
304 and speed of procedures while limiting complications and the number of pre-  
305 operative steps.

306 Sacrospinous hysteropexy has become an increasingly used surgical option for  
307 uterovaginal prolapse repair [4,5,7]. Moreover, gynecological surgeons are currently  
308 very interested in technological tools designed to facilitate the surgical procedures  
309 still lacking visual control and to improve their precision [27]. To our knowledge, no  
310 solution is yet available for sacrospinous fixation in vaginal prolapse repair.

311 A marker-based technology was chosen for obtaining the position of the different objects  
312 because of its reliability. Indeed, optoelectronic systems can be used in any  
313 environment, which is not the case of other technologies such as inertial measurement  
314 unit that may be sensitive to metal in their environment. In addition, its precision (below  
315 1 mm for each marker) makes it accurate enough for surgical applications [28].

316 Surgeons were more experienced with navigation than non-surgeons. Even if they  
317 did not have sacrospinous fixation experience, all of them had handled suture  
318 instruments or had experience with laparoscopy, as illustrated by their higher  
319 comfort score. However, this advantage did not seem to be related to a greater  
320 precision compared to non-surgeons, but rather to a greater speed. Surgeons had  
321 a greater awareness of the issues surrounding sacrospinous fixation. Their main  
322 objective was to find and hook the ligament nearby the ischial spine, as they  
323 would during an actual surgical procedure, in order to reduce the time and the risk of  
324 infection. While non-surgeons focused on getting the shortest distance to the  
325 target, even if it took them more time, surgeons focused on getting the most  
326 direct and therefore fastest trajectory, but not necessarily the most accurate.  
327 Although accuracy was not their main success criterion, almost half of the  
328 surgeon suture attempts were made with a precision objective during Session 1.  
329 Navigational aids were therefore effective to improve precision. In addition, the

330 display of red zones was also a relevant way to get participants to avoid highly  
331 vascularized and supplied with nerves areas. Indeed, the time spent in red zones  
332 was divided by 2 between both sessions.

333  
334 Even though all the surgeons rated the pelvis mock-up “bio-accurate enough for  
335 training”, some components must be improved to guarantee an effective training.  
336 The silicone used to mold the ligaments was flexible, whereas the sacrospinous  
337 ligament is one of the most rigid elements of the pelvic cavity. The perception of  
338 having hooked the ligament inside the mock-up was therefore less obvious than it  
339 should have been. Thereby, most participants had a great difficulty in “feeling” the  
340 ligament, as highlighted by the proportion of failures during the suturing phase.  
341 Moreover, the position of the target was defined on the ligament at rest. Thus,  
342 when the ligament deformed, there was a difference between the position of the  
343 target on the screen and its actual position, which was confusing. Participants  
344 also mentioned that an air-filled balloon was not the most accurate way to  
345 represent the organs, although at this point its purpose was only to get in the  
346 way of participants. In addition, during the pointing training phase, the suture  
347 was performed without the support of the ligament, which generated parasite  
348 movements when pressing on the suturing device piston. The performance was  
349 therefore underestimated compared to the accuracy actually achieved by  
350 participants. For such exercises, pressing on the piston should be optional.

351 The strength of this study is that it responds directly to a real need of  
352 gynecological surgeons to improve the position of their sutures and to their urge  
353 for teaching equipment, while limiting the ethical, financial, and safety issues to  
354 be considered. However, this study was of short duration, and the training period  
355 lasted only two one-hour sessions over one week. The results of the guidance  
356 performance were therefore underestimated. Moreover, it would be relevant to  
357 study the progression of performance over several sessions of a group of  
358 surgeons with a more homogeneous medical experience. In addition, the  
359 demarcation between the ligament and the sciatic spine was too obvious on the  
360 model, it was therefore not possible to compare our navigation method with  
361 palpation.

362

363 **Conclusion**

364 This new navigation method based on motion capture technology proved to be  
365 accurate and effective under the surgery-like conditions of our study. With practice,  
366 its users experienced a 20% improvement of their precision and speed and reported  
367 an easy-to-use software display. The next step of this project will be to design a  
368 pelvis model more adapted to the constraints of a sacrospinous fixation and to  
369 validate the benefits of this method compared to current techniques. In addition,  
370 further investigation must be done to improve the correlation between the MRI-  
371 based 3D-reconstruction of the pelvis and the imaging during surgery.

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472  
473 Our study is, according to French law, exempt from IRB approval since it did not include  
474 patients but voluntary participants and it is a non-interventional study

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477 **Figures and tables legends:**

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479 **Figure 1.** Components of the suturing device

480 **Figure 2.** Components of the pelvis mock-up

481 **Figure 3.** Participant suturing on the left ligament

482 **Figure 4.** Results of the post-experiment questionnaire

483 **Figure 5.** Distance according to the duration of the attempt for all successful attempts  
484 during the suturing phase.

485 **Figure 6.** Schematic diagram of the suturing phase

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490 **Table 1.** Population characteristics (n = 26)

491 **Table 2.** Mean distances per participant and progression of the performance of non-  
492 surgeons between Session 1 and 2.

493 **Table 3.** Mean duration of attempt per participant and progression of the performance  
494 of non-surgeons between Session 1 and 2.

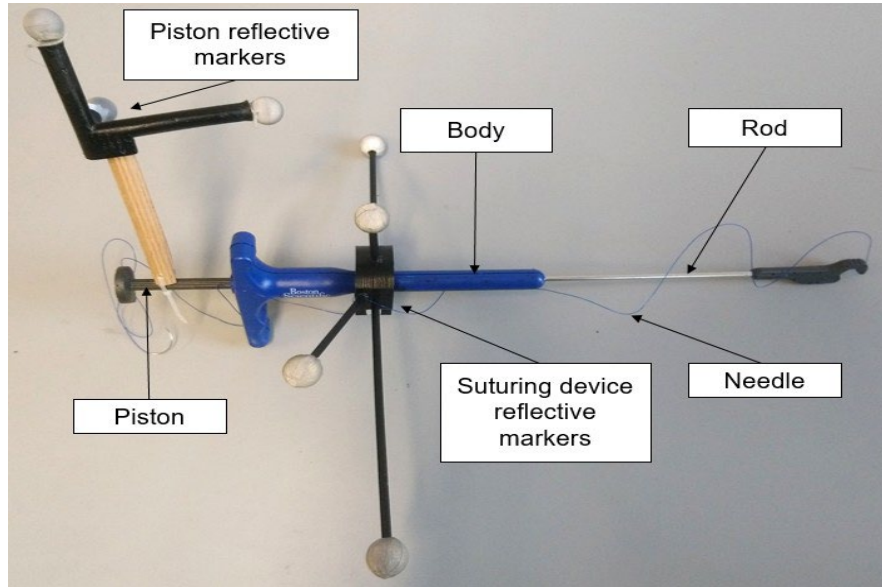
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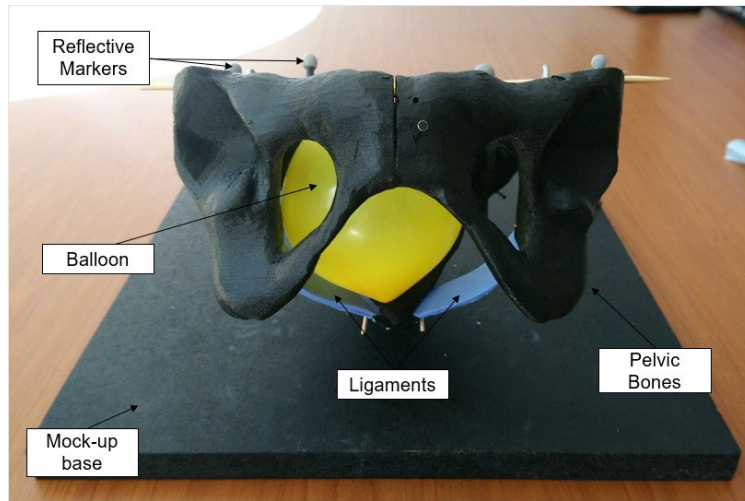
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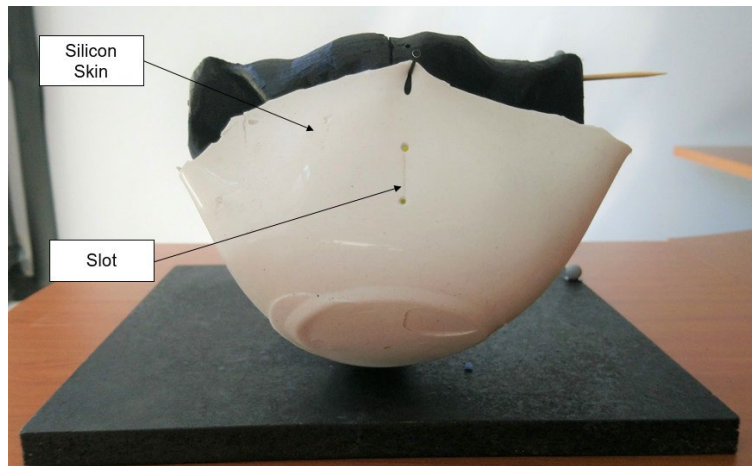
**Figure 1.** Components of the suturing device



**Figure 2.** Components of the pelvis mock-up



(a) Without skin

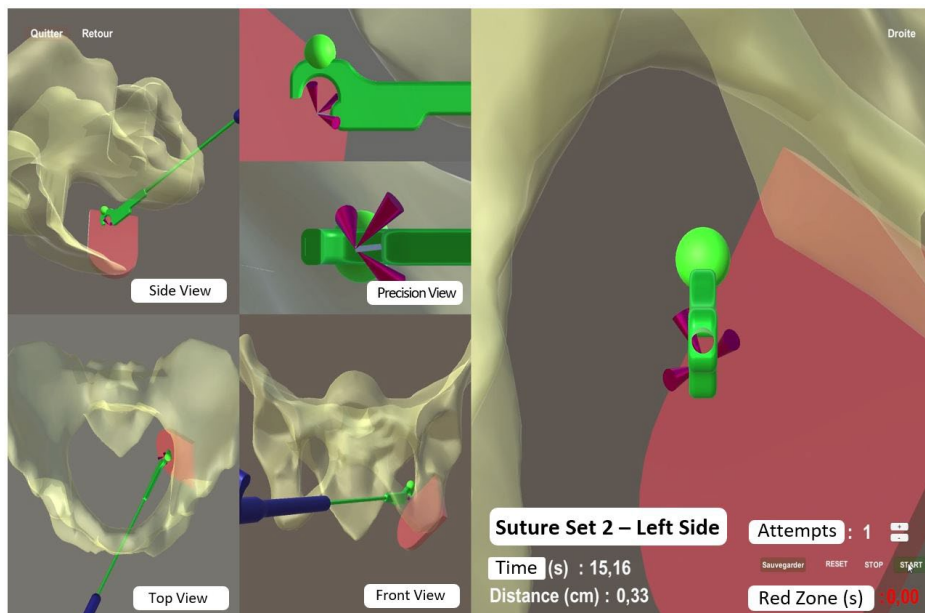


(b) With skin

**Figure 3.** Participant suturing on the left ligament

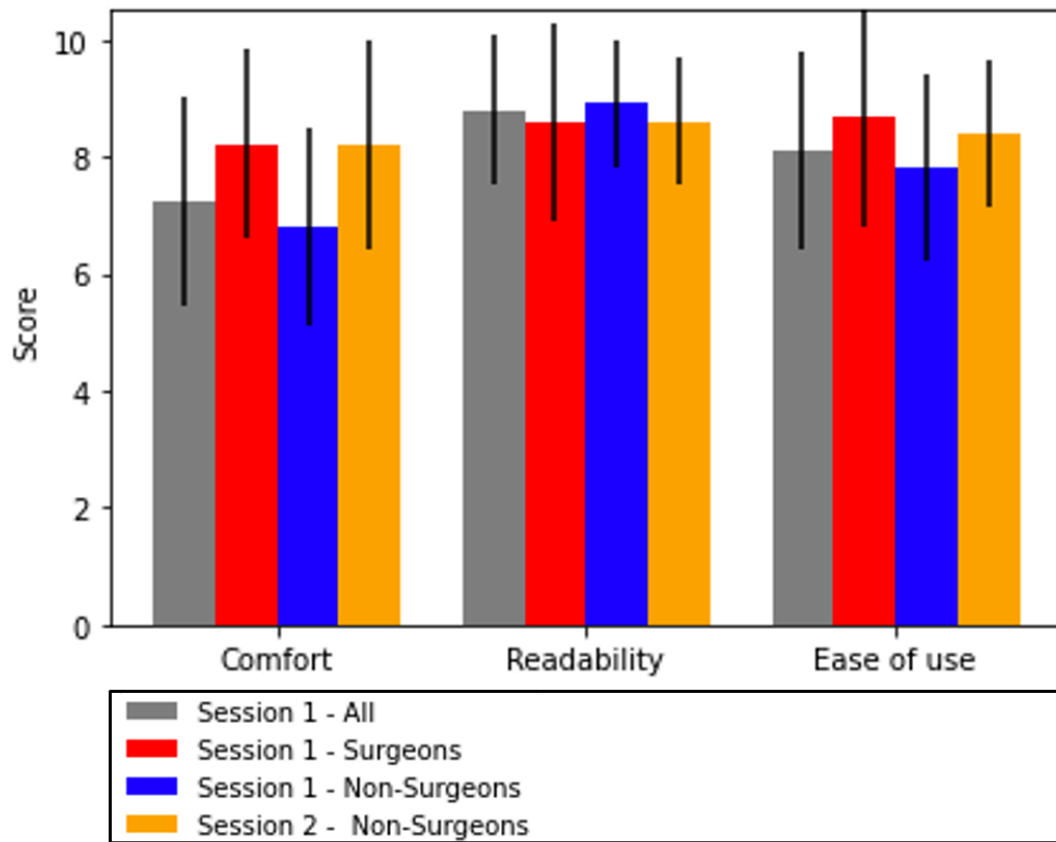


(a) The participant using the suturing device, while the pelvic mock-up is hidden by a curtain and the screen is displaying the information necessary for the participant to be guided to the target.



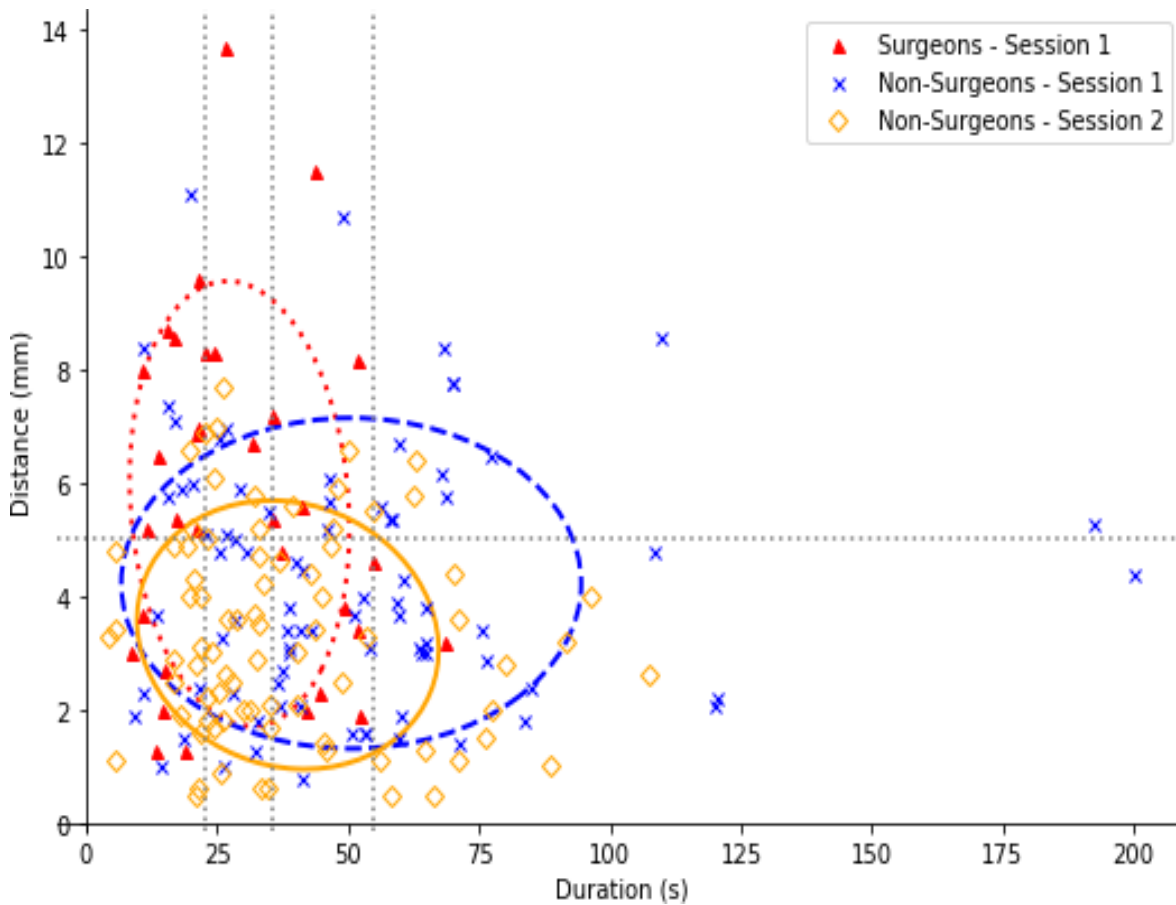
(b) Screen Display viewed by the participant with the suturing device tracked in real time, the pelvis geometry (based on a pre-operative MRI [magnetic resonance imaging] scan), the red zone, and the virtual target (defined by the summit of the three purple cones) set on the silicon ligament before the experiment. Of note, on this image, the suturing device is in position for suturing on the target.

**Figure 4.** Results of the post-experiment questionnaire



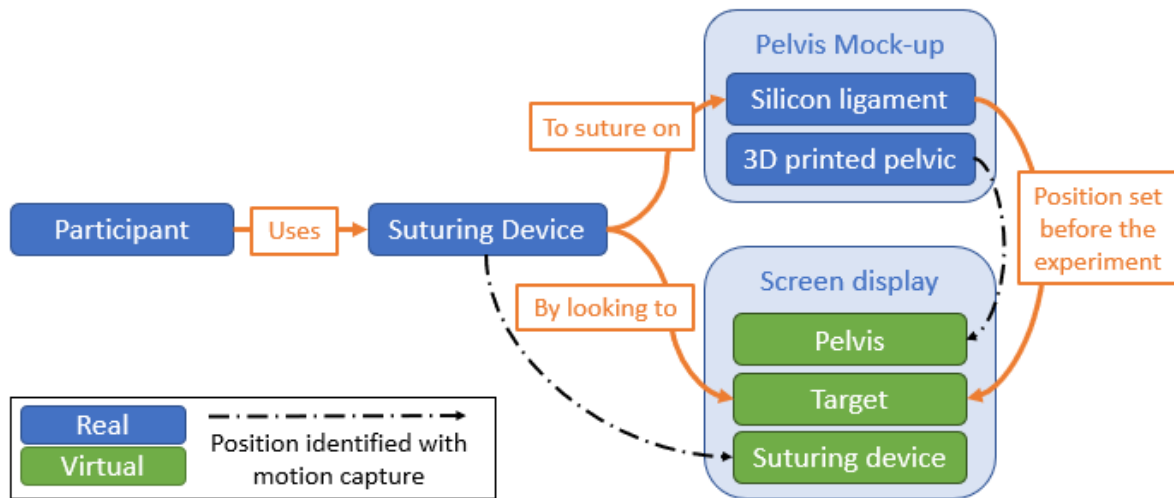


**Figure 5.** Distance according to the duration of the attempt for all successful attempts during the suturing phase.



**Legend.** The horizontal dotted line corresponds to the 5-mm accuracy threshold and distinguishes between the accurate and inaccurate successful attempts. The 3 vertical dotted lines correspond to the quantiles of duration and distinguish between “fast” (in the first two quantiles) and “slow” (in the last two quantiles) successful attempts. The colored dotted circles represent confidence ellipses around each group (standard deviation 1).

**Figure 6.** Schematic diagram of the suturing phase



**Table 1.** Population characteristics (n = 26)

	Surgeons (n = 9)	Non-Surgeons (n = 20)
Age	28 (26-44)	23 (19-30)
Gender		
Female	6 (66%)	9 (45%)
Male	3 (33%)	11 (55%)
Handedness		
Right	8 (89%)	17 (85%)
Left	1 (11%)	3 (15%)
Medical Background		
2 <sup>nd</sup> -year Resident	2 (22%)	
3 <sup>rd</sup> -year Resident	2 (22%)	
4 <sup>th</sup> -year Resident	1 (11%)	
Graduated for <5 years	3 (33%)	
Graduated for >10 years	1 (11%)	
SSF* experience		
on cadaver	2 (22%)	-
<i>in vivo</i>	2 (22%)	-

Data are expressed as median (range) or count (percentage).

\*SSF = SacroSpinous Fixation

**Table 2.** Mean distances per participant and progression of the performance of non-surgeons between Session 1 and 2.

	Distance (mm)					
	All	Surgeons	Non-surgeons			
	Session 1	Session 1	Session 1	Session 2	Progression	p
Pointing training	7 ± 2.5	7.6 ± 2.9	6.8 ± 2.4	4.6 ± 1.6	32%	10 <sup>-5</sup>
Suture training	5 ± 2.2	5.5 ± 3.3	4.8 ± 1.8	3.7 ± 1.7	23%	10 <sup>-5</sup>
Suturing phase	4.7 ± 1.8	5.7 ± 2.2	4.2 ± 1.5	3.3 ± 1.3	21%	10 <sup>-5</sup>
suture exercise 1	5.3 ± 2.1	6.6 ± 2	4.7 ± 2	3.4 ± 1.6	28%	10 <sup>-5</sup>
suture exercise 2	4.0 ± 1.8	4.7 ± 2.6	3.8 ± 1.3	3.2 ± 1.4	16%	10 <sup>-5</sup>

Data are expressed as mean ± standard deviation.

The progression between both sessions for non-surgeon participants corresponds to the following ratio: ([distance Session 1] - [distance Session 2]) / (distance Session 1).

**Table 3.** Mean duration of attempt per participant and progression of the performance of non-surgeons between Session 1 and 2.

Duration of attempts (s)

	All	Surgeons	Non-surgeons			
	Session 1	Session 1	Session 1	Session 2	Progression	p
Pointing training	30 ± 17	23 ± 14	32 ± 18	26 ± 15	19%	0.18
Suture training	43 ± 24	29 ± 9	46 ± 26	33 ± 16	33%	0.019
Suturing phase	44 ± 23	30 ± 14	50 ± 24	38 ± 19	24%	0.047
suture exercise 1	48 ± 32	32 ± 14	55 ± 35	40 ± 23	15%	0.034
suture exercise 2	41 ± 20	28 ± 14	46 ± 20	37 ± 18	20%	0.047

Data are expressed as mean ± standard deviation.

The progression between both sessions for non-surgeon participants corresponds to the following ratio: ([duration Session 1] - [duration Session 2]) / (duration Session 1).