Performance Evaluation to Improve Training in Forceps-Assisted Delivery

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Abstract. The World Health Organization recommends a rate of cesareans inferior than 15%. However, the actual rates in the US double this value, while the use of obstetrical instruments, a recommended alternative to cesareans but which requires high skill and experience, has significantly decreased in the latest years. In this context there is a clear demand for simulators, with special interest in learning the correct use of Kielland's forceps. In this work we present a virtual instrumented simulator to improve training in the correct use of forceps proposing a three-step protocol which guides users along the process while evaluating their performance. We validate this protocol, following principles based on previously published guidelines, on two types of manikins. Our results show that the proposed solution successfully detects the incorrect positioning of the forceps in most steps, guiding the user during the training process and providing feedback on wrong maneuvers.

Keywords: Training · Forceps delivery · Tracking system
Performance evaluation · Assessment

1 Motivation

According to the World Health Organization (WHO), the number of cesareans performed in deliveries should be inferior to 15% due to their associated intraoperative complications and morbidity [4]. Fifty years ago, this rate in the US was 4.5%. However, in 2009 it ascended to 32.9% and by 2015 the registered rate

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was 32.0% [7]. These fluctuations and the significant increment recorded over the last decades seem to be a consequence of the practice style.

The correct use of obstetrical instruments during the second stage of labor is a good alternative to cesarean, as it has demonstrated to reduce morbidity without increasing complications in the fetus. This reduction is especially significant when deliveries are forceps-assisted. However, the rates of operative vaginal delivery (OVD) have suffered an important reduction over the last decades, decreasing in the US from 9.01% in 1990 to 3.14% in 2015 [7]. The use of these tools for assistance requires high clinical experience and training, as poor performance can cause damage to both mother and fetus (skull or scalp trauma, facial nerve palsy or ocular trauma among others). Nowadays, health care providers seem to have a lack of experience when confronting real clinical cases which require the use of obstetrical instruments and, consequently, they may end up performing cesareans instead. A survey conducted among resident physicians upon completion of their residency showed that 55% of them did not feel competent to perform forceps and vacuum deliveries [9]. These results could explain the cesareans rate increment and the decrease of OVD.

A cross sectional study conducted in 2017 in the UK reported that more than two-thirds of specialist trainees in obstetrics and gynecology think simulators could improve training significantly in this area, showing special interest in the safe use of Kielland's forceps [12]. In our hospital, the number of cesareans in complicated cases has been reduced in recent years while the use of forceps (specially Kielland's) has increased considerably. This seems to be a consequence of the special attention given to train residents in the correct use of obstetrical instruments through manikins, actors and simulators.

Several simulators of childbirth have been developed over the years to complete novice obstetricians' formation. These simulators can be realistic and focus on different roles of childbirth. According to their components or features they can be classified as: anatomical or virtual and instrumented or non-instrumented. Anatomical simulators are useful for demonstration of obstetrical maneuvers and for learning how to handle specific scenarios. Instrumented anatomical simulators are more realistic, incorporating some interesting functionalities like the ability to replicate vaginal delivery by an ejection system [5]. On the other hand, virtual non-instrumented simulators include three-dimensional visualization, useful to illustrate the fetus descent, but are more theoretical than practical. Lastly, the virtual instrumented simulators are the most complex ones, including interaction between simulator and student by visual and/or haptic feedback.

Many virtual-instrumented simulators have focused on measuring shoulder extraction forces [8] while others simulate delivery with visual and haptic feedback [1]. Among these, some include a navigation component where the position of obstetrical instrumentation can be displayed in real time with respect to the manikins by means of a tracking system. The first to implement this functionality were Lapeer et al. in 2005 [6], developing an augmented reality interface where the forceps placement in the fetus manikin head could be visualized in a virtual scene using an optical tracking system. The purpose of their work was to evaluate skull deformations. In 2009 a new simulator called BirthSIM was presented including also instrumented forceps, tracked by means of an electromagnetic tracking system. Up to date, this seems to be the best augmented reality simulator for delivery training. However, their use of the tracked forceps has been limited to assess the improvements of junior obstetricians [2].

In this work we present a virtual instrumented simulator to improve training in the correct use of forceps. We propose a protocol composed of three steps which guide the users along the process while evaluating their performance. The evaluation principles applied are based on guidelines found in the literature as well as experts indications. The software has been developed in 3DSlicer [3] (a free and open-source platform for medical image analysis and visualization) for use in combination with delivery manikins. Forceps, fetus and mother are navigated through an electromagnetic tracker, while displaying their relative position in real time on a 3D virtual scene. To evaluate the protocol, two experiments were performed: one using a fixed manikin of a fetus head; the second, in a real scenario with delivery manikins and performed by an expert.

2 Materials and Methods

The 3D Guidance electromagnetic tracking system (EMTS) from NDI (Northern Digital Inc.) was used to track the position of the baby, mother and forceps blades in real time. We chose this type of positioning device instead of an optical tracking system as the former does not require direct view of the markers. As the baby is initially inside the mother and covered by the belly, the use of the EMTS was considered a better approach. However, the forceps are made of stainless steel, which alters the field generated by the EMTS due to its ferromagnetic properties. To overcome this issue, we 3D printed a replica of the forceps in Alumide, a non-ferromagnetic material commonly used in 3D printing composed of nylon filled with aluminum dust. Its model, extracted from a CT, was then modified to include in the handle endings a special case for the sensors. Also, four holes were added to the design of each blade for an accurate registration between sensor and model.

The PROMPT Flex - Advanced mother and fetus manikins (Limbs and Things) employed in our hospital for training workshops were used for experiments and for generation of the 3D models (from CT scan) visualized in the virtual scene. Also, a stand with the baby's head in occiput anterior (OA) position was 3D printed in polylactic acid (PLA) to carry out the initial experiment.

The software was implemented as an extension inside the open-source platform 3DSlicer. The extension is composed of different modules, each with a specific task: a registration module for setup, used to register each model with their corresponding sensor in a fast and semi-automatic way; a learning module to visualize the correct movement for each step; a training module to perform the process step by step while checking if the placements are correct; an evaluation module to record the whole process and analyze it afterwards.

In the following section, the steps taken during the process of forceps application will be explained, together with the description of how the verification has been implemented. By convention, the blade with the lock is referred to as left blade and the other as right. Figure 1 represents the reference system for each model present in the virtual scene.

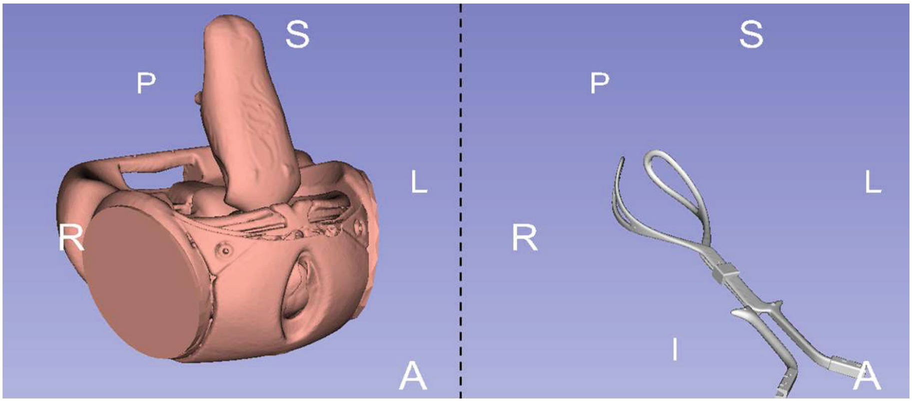

Fig. 1. Coordinate systems for mother and baby (left) and for forceps (right)

2.1 Protocol for Forceps Placement

Assembly and Presentation: Before the application, forceps are held outside the pelvis correctly assembled and presented in the position they will have once applied to the fetal head. For a correct assembly, the right shank must be above the left one and below the lock. The forceps should be placed symmetrically, being the handles at the same level. In the validation of this step, the relative position of the shanks is compared, taking the left forceps as reference frame. If the distances in horizontal or forwards are higher than 0.5 cm, the assembly is considered incorrect.

For a correct presentation, if the baby is placed in OA, the forceps should be parallel to the floor and the lock should be looking towards the fetal occiput (upwards). If the baby is in left OA or right OA position, the blades should form an angle of 45° with the floor. We defined a reference ideal position of the forceps with this criterium, and then calculated the registration between its actual position and this reference, extracting the rotational component of the resulting transform. For the presentation to be correct, the AP angle (measured in the reference frame of the baby) from the rotation matrix should be close to 0. As 45° would represent another position for the fetus, a margin of 22.5° (45/2) was established.

Forceps Application: The application of the forceps can be divided in three stages: initial placement, insertion and final placement. This is done firstly with the left branch and then with the right one in order to avoid them crossing once inserted, which can cause damage to the mother.

In the initial placement, the left blade is placed vertically and in contact with the fetus head. For detecting this contact, the distance between the tip of the forceps and the baby's head was computed and a maximum distance of 1 cm was defined as correct. The correct angle of the forceps was defined by an expert and settled to be 10° from the vertical (SI axis of the baby) with a 10° margin. For evaluation, the angle of a vector defined in the direction of the shank is compared with the ideal one.

Then, the insertion is performed. When completed, the blades should lie over the cheeks of the fetus covering the area between eyes and ears [10]. A study performed on 50 full term neonates showed that a margin of at least 3 cm should be kept between the tip of the blade and both the eye and facial nerve [2]. To verify a correct application, the distances from the tip to the outside eye corner and to the facial nerve (area behind the ear) are computed. Also, the distance from the tip to the cheeks is obtained, where values greater than 1 cm are considered incorrect.

Traction: Finally, after application both blades should be easily locked. Although the blades do not necessarily lock perfectly, the gap between the handles must be always below 1 cm [11]. Before performing the traction, the final position of the blades must be checked and the following conditions must be satisfied [10]: the midline of the forceps must coincide with the sagittal suture; the posterior fontanelle must be one finger breadth (2 cm) above the plane of the shanks; the space between the heel and the baby's head should admit no more than a fingertip (1 cm); the distance to eyes and facial nerve must be greater than 2.9 cm.

For validating that the forceps lie evenly against both sides of the baby's head and that the gap between them is 1 cm or less, the distance of each shank to the AP axis from the baby's reference frame is measured. The value should be between 0 and 0.5 cm for the left blade and between −0.5 and 0 for the right one. For measuring the distance to the posterior fontanelle, a plane is created in the shank, whose normal is defined by the vertical axis of the forceps coordinates system (SI). The distance between the fontanelle and the plane must be of at least 2 cm. The last two conditions enumerated are checked as explained in Step 2.

3 Experiments

For the protocol validation, an initial experiment was carried out by one of the members of the developers team using the printed forceps and the 3D printed head. Maneuvers for assembly, presentation and initial placement were repeated a total of 8 times, from which 4 were correctly placed while the other 4 were deliberately placed incorrectly. For final placement and traction, 4 correct placements were recorded.

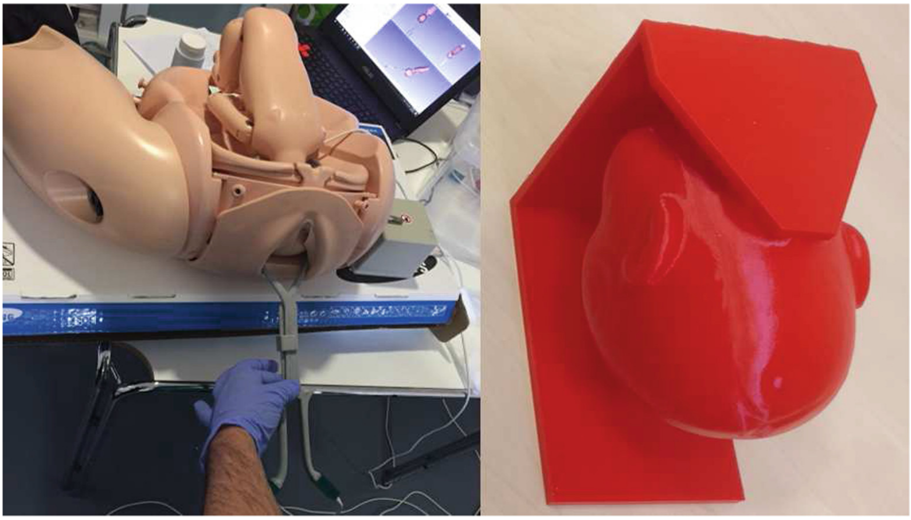

Fig. 2. Experiments with commercial manikins (left) and 3D printed head (right).

A second experiment was implemented in a real scenario, where maneuvers were performed by an expert (clinician with more than 14 years of experience in the field of obstetrics and gynecology) using the 3D printed forceps and the commercial manikins (Fig. 2). The number of recorded repetitions was the same as in the first experiment. For the deliberate incorrect placements and assemblies, the expert focused on common mistakes novices do when training. These examples were only for the first steps (before insertion) as common errors are easier to identify in these stages.

The precision and recall for each experiment were computed. In this application, precision is considered more relevant than recall as it is better for the training to inform the novice that the placement is incorrect when it is not than the opposite. For that reason, an $F_{0.5}$ score was evaluated defined as:

$$F_\beta = (1+\beta^2)\frac{Precision \cdot Recall}{\beta^2 Precision + Recall} \tag{1}$$

4 Results

Tables 1 and 2 show for each experiment the placements detected correctly (true positives and true negatives) and incorrectly (false positives and false negatives). These values are obtained for each phase of the procedure: assembly, presentation, initial and final placement (for left and right blades) and traction placement. Table 3 shows the resulting $F_{0.5}$ scores.

Table 1. Rates of success from experiment 1

	Step 1		Step 2				Step 3	Total
	Assembly	Presentation	Init L	Final L	Init R	Final R	Traction	
TP	2	4	4	2	4	1	3	**20**
TN	4	4	4	2	4	2	0	**20**
FP	0	0	0	0	0	0	0	**0**
FN	2	0	0	0	0	1	1	**4**

TP: true positive, TN: true negative, FP: false positive, FN: false negative
Init L(R): initial placement for left(right) branch
Final L(R): final placement for left(right) branch

Table 2. Rates of success from experiment 2 (expert)

	Step 1		Step 2				Step 3	Total
	Assembly	Presentation	Init L	Final L	Init R	Final R	Traction	
TP	3	4	4	1	3	0	0	**15**
TN	4	4	4	0	4	0	0	**16**
FP	0	0	0	0	0	0	0	**0**
FN	1	0	0	3	1	4	4	**13**

TP: true positive, TN: true negative, FP: false positive, FN: false negative
Init L(R): initial placement for left(right) branch
Final L(R): final placement for left(right) branch

Table 3. $F_{0.5}$ scores

	Precision	Recall	$F_{0.5}$
Experiment 1	1	0.83	**0.96**
Experiment 2	1	0.54	**0.85**

5 Conclusions

A new protocol for training in the correct application of forceps is presented. The implemented software goes through every step of the process and relies in the conditions presented in the literature and defined by experts to characterize the correctness of each step. An electromagnetic tracking system is used to track the position in real-time of forceps and manikins.

An initial evaluation of the software has been performed, firstly with a fixed manikin of a baby head in OA position and later in a real scenario with an expert using delivery commercial manikins. The results obtained from these experiments demonstrate high performance, especially for the initial steps. Yet, some limitations were found in the real scenario regarding the final placements. Once inserted, the forceps are slightly deformed, which implies an incorrect representation of the blades position in the virtual scene and therefore a wrong computation of the distances. This would explain the increase in the false negative rate for the final placement in step 2 and for step 3 during the second experiment, since the real manikin deformed the forceps during these phases.

In the lights of these promising results, a further study will be performed to assess the advantages in learning of forceps placement using this protocol. Also, an alternative more rigid material for the forceps will be tested to avoid deformation once inserted.

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