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Use of Knee Fractures Physical Replicas for Surgical Training and Rehearsal: Proof of Concept Study

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Abstract

In the last years also in orthopedic surgery, there was an increasing interest in the development of surgical simulators using methods of additive manufacturing combined or not with augmented reality systems (hybrid simulators). Aim of this work was to evaluate the use of a new patient's specific tibial plateau fractures simulator for surgical training of young resident surgeons in fracture fixation with an external fixator. The simulator is a realistic knee phantom including a patient-specific replica of a fractured tibia and fibula, obtained by CT segmentation and rapid prototyping techniques. Each training session started with the presentation, and planning, of the surgical case that it was followed by the external fixation session on the simulator. At the end of each session, all participants were asked to fill out a questionnaire, concerning the phantom realism and appropriateness as a teaching modality. The results of the Likert Questionnaire indicating that there is an overall significant agreement with the phantom realism and its appropriateness as a teaching modality. The solid model of the patient's anatomy can faithfully reproduce the surgical complexity of the patient and it allows to generate surgical simulators with an increasing difficulty to perform structured training paths: from the "simple" case to the "complex" case. The use of simulators based on 3D models has proved to be a very useful tool both for didactic and surgical training purposes, allowing surgeons to perform a real procedure simulation outside the surgical room.

Keywords: surgical simulation, surgical training, 3D printing, tibial fracture, additive manufacturing

1. Introduction.

To rapidly master evolving orthopedic surgical techniques requires long training times. The increasing pressure to reduce surgical risks, together with current work-hour restrictions and cost pressures, has raised the need for cost-effective structured training sessions, allowing trainees to acquire proficiency in a shorter amount of time and outside the surgical room. In the last years also in orthopedic surgery, there was an increasing interest in the development of surgical simulators using methods of additive manufacturing combined or not with augmented reality systems (hybrid simulators) [1-3]. Literature evidence supporting the educational advantages of surgical simulation in orthopedic skills training is increasing, showing positive effects on orthopedic residents' education and on maintaining the orthopedic surgeons' proficiency [4]. In orthopedic and trauma surgery some procedures can be performed with a low exposure of the target anatomy (i.e. percutaneous or mini-invasive procedures), and a fracture fixation using an external frame is one of these. In this kind of procedure, the presence of real anatomy, including vessels and nerves, as obtained using a cadaver, is less important than the presence of a patient's specific anatomy (i.e displaced fractures). Aim of this work was to evaluate the use of a new patient's specific tibial plateau fractures simulator for surgical training of young resident surgeons in fracture fixation with an external fixator.

2. Materials and methods.

The simulator is a realistic knee phantom including a patient-specific replica of a fractured tibia and fibula, and a reusable standard model of the femur, appropriately sized (from Sawbones). The manufacturing of patient-specific physical replica involves the elaboration of CT dataset and rapid prototyping techniques as described in previous work [1-3]. The stack of CT images in DICOM format is processed using a semi-automatic tool, the EndoCAS Segmentation Pipeline integrated into the open-source software ITK-SNAP 1.5, to generate the 3D virtual models of the patient bone structures. Then mesh optimization (e.g holes filling and mesh filtering) stages are performed via the open-source software MeshLab. A 3D printer

(Dimension Elite 3D Printer) is used to turn the 3D virtual models into tangible 3D synthetic replicas made of acrylonitrile butadiene styrene (ABS). This plastic is commonly used for the manufacturing of bone replica for orthopedic surgery simulation since, if properly printed, it sufficiently replicates the mechanical behavior of the natural tissue, and it is compatible with X-Ray examinations. Finally, a bone replica is embedded in soft synthetic polyurethane foam (via casting technique), covered with an RTV silicone-based skin-like layer, to allow accurate simulation of the bony anatomical landmarks palpation and surgical incision. For this preliminary study, 3 simulators were built selecting 3 different patterns of tibial plateau fractures and 5 orthopedic surgeons and 7 orthopedic resident surgeons were involved. We simulated a tibial plateau fracture fixation using an external fixator under fluoroscopic guidance.

Each training session started with the presentation, and planning, of the surgical case by an expert surgeon with the examination of the patient radiological images. This presentation was followed by the external fixation session on the simulator [FIG1]. At the end of each session, all participants were asked to fill out a questionnaire, concerning the phantom realism and appropriateness as a teaching modality. The questionnaire comprises 9 items assessed using a six-point Likert scale (1= strongly disagree to 6 strongly agree) grouped under 2 headings: Face Validity Evaluation (realism of the simulator) and Content Validity Evaluation (appropriateness as a teaching modality). Statistical analysis of data was performed using the SPSS® Statistics Base 19 software.

Fig. 1

3. Results

The results of the Likert Questionnaire indicating that there is an overall significant agreement with the phantom realism and its appropriateness as a teaching modality [TAB1]. A positive opinion was obtained regardless of the operator's level of experience: all participants (both expert surgeons and residents) expressed a positive opinion on all items of the questionnaire. Moreover, as highlighted by the Wilcoxon test, there is no statistically significant difference in responses depending on the experience of the participant (p values>0.05 for all items). The Kruskal-Wallis H test reveals that there is no statistically significant difference between the responses expressed for the three different cases, neither for the group of surgeons nor for the group of resident surgeons (p-value >0.05 for all item as reported in table 1): this could be interpreted as a demonstration of the robustness of the proposed strategy for the fabrications of simulators.

		Median (IQR) FOR SURGEONS				Median (IQR) FOR RESIDENT SURGEONS				Median (IQR) OVERALL			
		Sim. 1	Sim. 2	Sim. 3	K. W p-value	Sim. 1	Sim. 2	Sim. 3	K.W p-value	Sim. 1	Sim. 2	Sim. 3	TOT
FACE VALIDITY EVALUATION	1) the phantom is globally realistic	5 (5;5)	5 (5;5)	5 (5;5)	1.000	5 (5;5.25)	5 (5;5)	6 (5.5;6)	0.091	5 (5;5)	5(5;5)	5 (5;6)	5 (5;6)
	2) the bone replica inside the phantom are realistic	5 (5;5)	5 (5;5)	5 (5;6)	0.727	5.5 (4.75;6)	6 (5;6)	5 (5;5.5)	0.696	5 (5;6)	5 (4.75;6)	5 (5;6)	5 (5;6)
	3) the manufacturing material of the hip replica allows a realistic interaction with the surgical instrumentations	5 (5;5)	5 (5;5)	4 (4;5)	0.265	5 (4.75;5.25)	5 (5;6)	6 (5.5;6)	0.195	5 (4.75;5.25)	5 (4.75;6)	5 (4.75;6)	6 (5;6)
	4) the phantom includes all the anatomical components necessary to simulate the target intervention	6 (5;6)	6 (5;6)	4 (4;5)	0.106	6 (5.75;6)	6 (5;6)	6 (5;6)	0.913	6 (5;6)	5 (4;6)	5 (4.75;6)	6 (5;6)
	5) the simulated intervention on the phantom is not more difficult than the real intervention	5 (4;6)	5 (4;6)	6 (4;6)	0.922	5 (5;5.25)	5 (5;5.5)	6 (5;6)	1.000	5 (4.75;6)	5 (5;6)	5 (4.75;6)	5 (4.75;6)
CONTENT VALIDITY EVALUATION	6) the phantom is useful to improve the learning process of external fixation procedure	6 (6;6)	6 (6;6)	6 (6;6)	0.584	6 (6;6)	6 (6;6)	5 (5;5.5)	0.329	6 (6;6)	6(6;6)	6 (6;6)	6 (6;6)
	7) a training course based on the use of such kind of phantoms is useful for orthopedic resident surgeons	6 (6;6)	6 (6;6)	6 (5;6)	0.727	6 (6;6)	6 (5;6)	6 (5.5;6)	0.513	6 (6;6)	6 (5;6)	6 (5;6)	6 (5;6)
	8) I share the rationale of using the phantom for surgical simulations	6 (6;6)	6 (6;6)	6 (6;6)	0.985	5 (5;6)	6 (5.5;6)	6 (5;6)	0.683	6 (5;6)	6 (6;6)	6 (5;6)	6 (5;6)
	9) I would use the phantom for a training course	6 (6;6)	6 (6;6)	6 (6;6)	0.985	6 (5.75;6)	6(6;6)	6 (5;6)	.513	6 (5,75;6)	6 (6;6)	6 (5;6)	6 (5.75;6)

Tab. 1 shows the results of the Likert Questionnaire indicating that there is an overall significant agreement with the phantom realism and its appropriateness as a teaching modality

4. Discussion and conclusion.

The solid model of the patient's anatomy can faithfully reproduce the surgical complexity of the patient and it allows to generate surgical simulators with an increasing difficulty to perform structured training paths: from the "simple" case to the "complex" case. A growing number of papers point to the evidence that pre-operative planning, young surgeons education and the act of surgery itself can be improved by 3D printed simulators: these papers explore the use of 3D-printing assisted surgical planning in a plethora of fields, from maxillofacial to spinal surgery [5-7]. As Tack *et al* described in their review, beneficial findings for 3D printed anatomical models have been reported unanimously, improving preoperative planning and clinical outcome while reducing the exposure to ionizing radiation. [8]. The results of our preliminary study showed that the use of patients specific simulators represents a new opportunity that, unlike cadaver training, allows to choose in advance from a patient's library the degree of complexity of the case and to adapt it to the level of the surgeon's experience (from basic courses to advanced courses). The use of simulators based on 3D models has proved to be a very useful tool both for didactic and surgical training purposes, allowing surgeons to perform a real procedure simulation outside the surgical room.

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