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The trends and challenges in orthopaedic simulation

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ARTICLE INFO

Article history:

Received 22 March 2015

Accepted 24 May 2015

Available online 19 June 2015

Keywords:

Orthopaedics

Simulation

Fracture complexity

O3DC

ABSTRACT

Generally, in some universities of medicine, orthopaedic training procedures represent a difficult task due to the inadequacies of the systems, the resources, and the use of technologies. This article explains the challenges and the needs for more research in the issue of orthopaedic simulation around the world.

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The Making of a Cardiothoracic Surgeon: An Apollonian Quest (Aldo R. Castaneda)

1. Orthopaedic research in the past 50 years

In the last decade, literature has shown that the medical research is based on simulation-based medical education (SBME). The points that are treated by the researchers include: feedback, teamwork, skills acquisition and simulation fidelity. According to Azevedo and Bernard,¹ the feedback used in educational contexts is generally regarded as crucial to improving knowledge and skills acquisition. There are two types of feedback which are formative² and summative.³ Most of the feedback is formative in order to improve the performance of surgeons. The objective is to identify the gap between programs of training and the progression of technologies, to clarify the clinical outcomes and to diagnose the misunderstandings in learning. The Fig. 1 illustrates the formative feedback taking account the context and characteristics of the learner. The informations concerning the

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<http://dx.doi.org/10.1016/j.jor.2015.05.014>

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Fig. 1 – Feedback.

learner are important that include skills and academic motivation (see Fig. 2).

The problems of the formation of a teamwork increase because of the communication between surgeons and other specialists which has an impact on the quality, safety, and

outcome in orthopaedic simulation. The communication includes the procedures, data analyses, results, and error analyses. We can speak of "interdisciplinary" team work. Stephen et al⁴ explain the importance of Emergency Medicine (EM) and its effect on clinician performances, the increase of the patient safety, and decrease of liability. Today, the collaborative effort has become a necessity to align with the complexity of surgical expertise. Three categories have been mentioned for assessing surgical performances which are technical skills, clinical skills, and social skills. Kopta⁵ defines the technical skills in three phases: cognitive, integrative, and autonomous. The cognitive phase is composed of three components (observation, coaching, and practice) that are performed by the student (reflecting, exploring, etc.). In the second phase, the student was engaged to communicate with team members and to clarify the results. Moreover, automation is achieved if the surgeon practices the same process several times. Lippert⁶ thinks that technical competencies are achieved through reviews of surgical books and medical journals. The surgeon needs a background of knowledge such as the ability of directing, organizing, and coordinating to avoid communication failures and to improve the knowledge of the situation.⁷ Ethan et al⁸ discuss the relationship between surgical hand training and sign language learning. They proved that

Table 1

Scores on examinations for technical and cognitive skills

Test	Mean group score, % (& SD)		Group difference,* % (& SD)	
	Technical	Cognitive		
Pre-course technical skills (average of 2 normal knees)				
	Task-specific checklist	27 (24)	26 (26)	-1 (25)
	Global rating scale	22 (16)	19 (19)	-3 (17)
	End-product analysis	26 (32)	15 (15)	-11 (25)
Postcourse technical skills				
Normal knee	Task-specific checklist	83 (10)	83 (13)	0 (12)
	Global rating scale	70 (24)	72 (14)	2 (20)
	End-product analysis	81 (15)	80 (17)	-1 (16)
Arthritic knee	Task-specific checklist	88 (12)	77 (14)	-11 (13)
	Global rating scale	68 (19)	62 (17)	-6 (18)
	End-product analysis	83 (10)	78 (25)	-5 (19)
Difference from pre-course test				
Normal knee	Task-specific checklist	56 (25)	57 (28)	1 (26)
	Global rating scale	48 (24)	53 (19)	5 (22)
	End-product analysis	55 (40)	65 (26)	10 (34)
Arthritic knee	Task-specific checklist	61 (26)	51 (21)	-10 (24)
	Global rating scale	46 (21)	43 (24)	-3 (22)
	End-product analysis	57 (27)	63 (24)	8 (26)
Cognitive skills (post-course only)				
	Multiple-choice	57 (16)	62 (10)	5 (13)
	Error-detection	57 (20)	76 (10)	19 (16) [†]

*None of the differences seen between groups were statistically significant, except for [†]*p* = 0.02.
SD = standard deviation

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Fig. 2 – Scores on examinations for technical and cognitive skills.⁹

Fig. 3 – Michael Gordon with Harvey in the early 1970.¹⁵

technical skills are acquired if the student answers questions such as why the surgeon uses his right hand to node in a suture and what the effect of node tightening is. To measure the technical skills of a surgeon, we need an assessment process. Generally, this process is achieved outside the operation room using the OSATS method (Objective Structured Assessment of technical Skill) to assess the performance of a student. This evaluation method requires a control list and a scorecard.⁹ Another technique, for instance, is used at the University of McGill for student evaluation training during a laparoscopy operation. This technique depends on the numbers of gestures. The observers put sensors on the hands of a student to count the achieved movements while performing a basic surgical task.¹⁰ The student, who performs an operation with minimal gestures possible, is a good future surgeon. Clinical skills are built upon the analysis and understanding of the treatment process. This is based on three levels: 1) the mere recollection of facts, 2) the interpretation of data, 3) the problem resolution. Students who successfully acquire these skills must perform the required tasks in a systematic, organized, and precise way. During the last 30 years, there has been a growing interest among surgeons for these competencies. Furthermore, ECOS (Examen Clinical Objective Structured)¹¹ is a test designed to measure the performance of the trainees in clinical situations. Actually, students must complete a series of tasks under the control of a supervisor. The evaluation covers many aspects including the abilities to

question, the conduct of diagnoses, the organization of the communication, the complementary investigation, etc. The following table shows an example of evaluation of the exam OSATS.

CABLE (Cognitive apprenticeship based learning environment) is another modern method to acquire clinical concepts. It has provided the opportunity to use computer tools. It also represents an interface which concludes both contextual and non-contextual scenarios to acquire skills from this discipline.^{12,13} The clinical and technical skills are not enough. Human skills have a crucial importance in surgical training.¹⁴ In fact, a good surgeon must not give negative information (risk, complications, etc.) to his patients. However, he may explain to the patients the difference between the wishes of recovery and real possibilities. He must also take in consideration the desire of living of the patient.¹⁵

First, we will explain the difference between simulation and simulators to avoid any confusion between these two terms. The simulator is linked to the technologies that can give the user an immersive environment. The simulation is an application of simulators. Several professors have mentioned that the simulation has brought tremendous changes in the mentality of the surgeons. The present invention related to simulation fidelity (SF) provides training for surgeons. The performance of SF is based on two concepts which are resources and technologies. The resources are classified into four categories: mannequins, medical images, computer-aided design (CAD), and mathematical models.

Small et al,⁴ define that the mannequin patient has a mouth, pharynx, larynx, bronchial tubes, and esophagus that are anatomically representative of a human patient. Cooper et al¹⁶ give an overview of the history of the development of a mannequin (see Fig. 3).

In this section, we will give an overview of the different medical images used in the orthopaedic simulation. Each image has different characteristics and the use depends on the desired application. X-rays were discovered in 1895 by Roentgen.¹⁷ Their objective was the production of topographic images. The X-rays scan the patient's body where a part of this beam is absorbed by the structure and another part is transferred to the computer using a sensor. Computed Tomography (CT) scan uses the X-rays technique to visualize the details and obtain digital information about the structure geometry (see Fig. 4).

MRI (Magnetic Resonance Imaging)¹⁹ is a medical imaging method which uses the properties of nuclear magnetic resonance (NMR) to view the details deep inside a human body

Fig. 4 – Computed tomography.¹⁷

Fig. 5 – Magnetic resonance Imaging.¹⁹

part. NMR is based upon the acquisition of the radiation of radio frequency (RF) (see Fig. 5).

The purpose of the use of medical imaging is to find multi-modal quantitative information in order to simulate and perform a correct gesture accurately. The problem is how to deal with these images. The surgeons must ask some questions: What can I extract from these images? How can I see the small fractures? How can I measure the depth of the fracture? 3D reconstruction helps surgeons to understand the important anatomical structures (nerves, vessels) and anatomical properties (length, angles, anatomical axis). The modern approach to biomechanical modeling study suggests the use of numerical analyses, which takes into account the anatomical parameters of bone and physical properties of

tissues. This method allows the use of basic laws of physics, mechanics, mathematics, biology, physiology and other sciences. It explains the functional structure of the process under study and the internal organization, reveals its essential connection with external objects and assesses the quantitative characteristics. Calculations, the development of computer science and the use of imaging technology can increase the efficiency of simulation and modeling orthopaedic. There are several tools for modeling bones and interaction between them. The Finite Element Method (FEM)²¹ is a numerical method for solving differential equations with partial derivatives and integral equations arising in the solution of problems in applied physics. The method is widely used for solving problems of solid mechanics, heat transfer, fluid dynamics and electrodynamics. The choice of this method is justified. The FEM is mostly versatile in terms of geometry modeling systems which includes various material properties calculation of its constituent parts. The latitude modeling of load and boundary conditions also make it more versatile.²² The general theory of modeling suggests the possibility of building a complex mode (e.g., inclusion of the maximum number of parameters in the model).²³ Bones must take into account geometric and anatomical features. The process of modeling any object begins with geometric constructions (see Fig. 6).

In literature, there are many virtual reality systems that have been built for drilling simulation.²⁴ Generally, the system emphasizes a feedback force. This technology represents the first condition for the success of simulation in terms of surgeon's evaluation. We can cite the example of HOOT (Haptic Orthopaedic Training) Simulator,²⁵ which aims to provide to surgeons a good training, especially in drilling (see Fig. 7).

Fig. 6 – Finite element simulation of bone.

Fig. 7 – HOOT (haptic orthopaedic training) simulator.²⁴

2. Need to align with the progression of fractures complexity

There is a lot of classification which are cumbersome and inaccurate for most surgeons. The question arises: how can I classify this type of fracture? Is it a good classification? How can I validate it? In fact, complex fractures are related to multiple bones that require intensive treatments. Edelson et al²⁶ explain the importance of 3D concept for the classification using 3D CT reconstruction technology. Likewise,

researchers of Universidade Federal de São Paulo, Brazil focus on the complexity of the fractures of the humerus' proximal extremity. Matsushigue et al²⁷ mentioned that the difficulty of classification includes the evaluation of angulation and the degree of displacement using a radiograph which is characterized by poor information. Facing this reality, the use of computed tomography (CT) can improve the evaluation of these fractures. The classification categories are organized as follows: extra-articular single-focus fractures, extra-articular bifocal fractures and joint fractures (see Fig. 8).

3. Evolving challenges in the orthopaedic field

The problems of orthopaedics don't limit a fracture complexity, but there are other difficult questions that the surgeons must think about. For example Osteosarcoma becomes a most common malignant primary neoplasm of bones.²⁸ It requires a multidisciplinary treatment.²⁹ Ding et al³⁰ explained the outcomes of the use of computer-aided design for the resection of tumors around the knee. This technique allows the surgeons to remove precisely the tumor. Several steps must be identified to achieve a good result: (1) the identification of the tumor's range using two types of data: the 2D CT to reconstruct a 3D anatomical model of bone and the 2D MRI to reconstruct a 3D Model of the tumor's region. (2) The template to guide accurate tumor resection. Sometimes

Fig. 8 – Diagram of the five basic types of fracture in the 3-D classification.²⁵

Fig. 9 – Orthognathic Surgery.³⁰

the use of CAD for the development of orthopaedic surgery does not seem obvious. In the case of craniofacial and maxillofacial surgeries, the reconstruction of the model in three-dimensional is a complex task. The difficulty is to create a template which verifies two notions: the reduction of operative time and accurate postoperative results (see Fig. 9).

4. Our direction: Orthopaedic 3D Collection (O3DC)

Orthopaedic training is undergoing a paradigm shift. The design of orthopaedic simulators is a difficult task due to the models of the bones, the types of fractures, and the complex geometry of the instruments used to perform those fractures. Our goal is to provide surgeons a platform that contains models to perform specific tasks with an efficient use. Today, the absence of orthopaedic collection limits the possibility of simulation. O3DC aims to provide access to all models of bones in the human skeleton, taking into account the size, shape and mechanical properties. Models of 3D-objects can be provided by Kinect, 3D scanner and software (CAD/CAM/CAE). The realization of this collection entails many difficulties:

1. Large range of 3D objects. There are 220 bones in the human body and many different tools for surgery.
2. A huge number of types of fractures which must be grouped and classified in 3D.
3. The problem of simulation of bone's properties. The spatial arrangement of collagen structures³¹ is one of the most important factors in the formation of bone mechanical properties. Simulation in the case of anisotropic structure is not reliable. Anisotropy of tissues associated primarily with a certain order in the arrangement of the structural elements.
4. Huge spreads of sizes and anatomical features. For example, voltage distribution patterns within the bone depends on geometrical parameters. There is a change in the structure of a long bone. This ensures a smooth change in rigidity and uniform transmission of pressure from the bone through the surface of hyaline cartilage and synovial joint fluid.
5. The complexity and variety of properties of materials: to simulate the reactions of bone to physiological and non-

physiological load conditions, we need an exact description of the material. In literature, 300 published studies are treated the material properties of human cadaverous.³²

This collection should also contain evaluation techniques for each simulation to analyze better the gestures of surgeons. The project is not limited to surgeons, but also to guide experts and product designer in the development of 3D tools and techniques. A step of processing of 3D objects can improve the quality of rendering. An algorithm of articulation of some tools of surgery such as drills and scissors will be proposed to give surgeons a more practical simulation.

5. Conclusion

Advances in scientific health will come from the acquisition of new knowledge in a number of areas. Nevertheless, it is useful to recall some major issues and elements. We need an extraordinary acceleration of production data, the emergence of powerful new research such as mathematics, computer science, and orthopaedic. Also, we need to redefine the training and we must be at the same level of new simulation technique. For this reason, the funding of biomedical research requires strong attention of the university and medical centers for a high-impact innovations.

Conflicts of interest

The author has none to declare.

REFERENCES

1. Azevedo R, Bernard RM. A meta-analysis of the effects of feedback in computer-based instruction. *J Educ Comput Res.* 1995;13:111–127.
2. Heritage M. Formative assessment. What do teachers need to know and do? *Phi Delta Kappan.* 2007;140–145.
3. Wakefield C, Adieb J, Pittc E, Owens T. Feeding forward from summative assessment: the essay feedback checklist as a learning tool. *Assess Eval High Educ.* 2014;39:253–262.

4. Small DS, Wuerz RC, Simon R, Shapiro N, Conn A, Setnik G. Demonstration of high-fidelity simulation team training for emergency medicine. *Acad Emerg Med*. 2008;6:312–323.
5. Kopta JA. The development of motor skills in orthopedic education. *Clin Orthop*. 1971;75:80–85.
6. Lippert 3rd FG, Spolek GA, Kirkpatrick GS, Briggs KA, Clawson DK. A psychomotor skills course for orthopaedic residents. *J Med Educ*. 1975;50:982–983.
7. Reason J. *L'erreur Humaine*. France: PUF; 1993.
8. Grober ED, Jewett MAS. The concept and trajectory of operative competence in surgical training. *Can J Surg*. 2006;49:238–240.
9. Kohls-Gatzoulis JA, Regehr G, Hutchison C. Teaching cognitive skills improves learning in surgical skills courses: a blinded, prospective, randomized study. *Can J Surg*. 2004;47:277–283.
10. Sanson D, Vleuten C. Assessment of clinical skills with standardized patients: state of the art. *Teach Learn*. 1990;2:58–76.
11. Collins A, Kesselman C, Nick J, Tuecke S. *Cognitive Apprenticeship and Instructional Technology*. Technical report. Centre for the Study of Reading, University of Illinois; 2007.
12. Cooper JL, Prescott S, Cook L, Smith L, Mueck R, Cuseo J. *Cooperative Learning and College Instruction: Effective Use of Student Learning Teams*. Technical report. California State University Foundation on Behalf of the California State University Institute for Teaching and Learning; 1990.
13. Chatelard S. *Psychosocial Skills in General Practice Deal with Health Inequalities: Literature Review*. Technical report. Joseph Fourier University, Faculty of Medicine of Grenoble; 2011.
14. Sarwer DB, Wadden TA, Pertschuk MJ, Whitaker LA. The psychology of cosmetic surgery: a review and reconceptualization. *Clin Psychol Rev*. 1998;18:1–22.
15. Cooper JB, Taqueti JBTM. The watershed transform: definition, algorithm, and parallelization strategies. *J Fundam Informaticae*. 2000;41:187–228.
16. The University of Texas CT Lab, \url{http://www.ctlab.geo.utexas.edu}.
17. Meijster A, Rontgen VR. A brief history of the development of mannequin simulators for clinical education and training. *Fundam Inf*. 2000;41:187–228.
19. Mouloupoulos BLA, Mouloupoulos MA. Magnetic resonance imaging of the bone marrow in hematologic malignancies. *Blood*. 1997;90:2127–2147.
21. Lewinstein I, Banks-Sills L, Eliasi R. Finite element analysis of and new system (IL) for supporting an implant – retained cantilever prosthesis. *Int J Oral Maxillofac Implants*. 1995;10:355–366.
22. Herzog W. *Individual Muscle Force Prediction in Athletic Movements*. PhD Thesis. The University of Calgary; 1995.
23. Tsai MD, Hsieh MS, Tsai CH. Bone drilling haptic interaction for orthopedic surgical simulator. *Comput Biol Med*. 2007;37:1709–1718.
24. Imperial College London, {http://www1.imperial.ac.uk/simms/research/procedure_modelling_simulation/hoot/}.
25. Edelson g, Kelly I, Vigder F, Reis ND. A three-dimensional classification for fractures of the proximal humerus. *J BONE Jt Surg*. 2004;86:413–425.
26. Matsushigue T, Pagliaro Franco V, Pierami R, Tamaoki MJS, Netto NA, Matsumoto MH. Do computed tomography and its 3D reconstruction increase the reproducibility of classifications of fractures of the proximal extremity of the humerus? *Rev Bras Ortop*. 2014;49:174–177.
27. Jaffe N. Osteosarcoma: review of the past, impact on the future. The American experience. *Cancer Control*. 2008;15:239–262.
28. Marulanda GA, Henderson ER, Johnson DA, Letson GD, Cheong D. Orthopedic surgery options for the treatment of primary osteosarcoma. *Cancer Treat Res*. 2008;152:13–20.
29. Ding HW, Yu GW, Tu G, et al. Computer-aided resection and endoprosthesis design for the management of malignant bone tumors around the knee: outcomes of 12 cases. *BMC Musculoskelet Disord*. 2013;152:1–9.
30. Levine JP, Patel A, Saadeh PB, Hirsch DL. Computer-aided design and manufacturing in craniomaxillofacial surgery: the new state of the art. *J Craniofacial Surg*. 2012;23:288–293.
31. De Bont LGM, Boering G, Havinga P, Liem RSB. Spatial arrangement of collagen fibrils in the articular cartilage of the mandibular condyle: a light microscopic and scanning electron microscopic study. *J oral Maxillofac Surg*. 1984;42:306–313.
32. Wirtz DC, Schiffers N, Pandorf T, Radermacher K, Weichert D, Forst R. Critical evaluation of known bone material properties to realize anisotropic FE-simulation of the proximal femur. *J Biomechanics*. 2000;33:1325–1330.