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Replacement methods of the animal model in the education of surgical techniques: a review

Substitutivos do modelo animal no ensino de técnica cirúrgica: uma revisão

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ABSTRACT: The use of live animal models in teaching surgical technique in medical schools was reduced due to bioethical debate. Thus, alternatives are necessary for the quality of training to be maintained. To carry out a bibliographic review on the alternative methods to the animal model for the teaching of the surgical technique in the course of medical graduation. A review of the bibliography was carried out in scientific articles published on the platforms *SciELO, PubMed, Google Scholar,* BVS-Vet, BIREME in the last 15 years. There are several models that have been developed as an alternative for the use of live animals in the teaching of surgical technique. They range from synthetic fabric for suture training, through chemically preserved corpses and models printed by 3D printers, to computer simulators. The current models, whether synthetic, 3D models or simulators, still have certain limitations, but with the advent of new technologies new alternatives will emerge and certainly complement effectively the teaching of surgery in medical schools.

Keywords: Education, higher; Education, medical; Simulation training; Models, anatomic; Models, structural; Printing, three-dimensional.

RESUMO: A utilização de modelos animais vivos no ensino da Técnica Cirúrgica nas Escolas de Medicina foi reduzida devido principalmente ao debate bioético. Assim, são necessárias alternativas para que a qualidade na formação do acadêmico se mantenha adequada. O objetivo do artigo foi proceder uma revisão na literatura atual sobre os métodos alternativos ao modelo animal vivo para o ensino da Técnica Operatória no curso de graduação em medicina, considerando a relação custo /benefício. Para isso, foi realizada uma revisão da bibliografia em artigos científicos publicados nas plataformas *SciELO*, *PubMed*, *Google Acadêmico*, BVS-Vet e BIREME, nos últimos 15 anos, com uso dos descritores: Ensino médico; treinamento com simulador; modelos cirúrgicos; modelos estruturais; impressão em 3D. Existem diversos modelos que foram desenvolvidos como alternativa para o uso de animais vivos no ensino de técnica operatória. Eles variam desde tecido sintético para treinamento em suturas, passando por cadáveres quimicamente preservados e modelos impressos por impressoras 3D, até chegar aos sofisticados simuladores computadorizados. Os modelos existentes atualmente, seja o sintético, os modelos 3D ou os simuladores, ainda apresentam certas limitações, mas com o advento das novas tecnologias novas alternativas estão surgindo e, com certeza complementarão de forma eficaz o ensino de cirurgia nas Escolas de Medicina.

Descritores: Educação superior; Educação médica; Treinamento por simulação; Modelos anatômicos; Modelos estruturais; Impressão tridimensional.

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INTRODUCTION

The teaching of the Surgical Technique in Medical Schools has always been characterized by an extensive practical workload, and these are often taught with the use of live animals to demonstrate the surgical technique in question for students, and then the students themselves for the development and acquisition of surgical skills[1].

The fundamental operations for systematic execution of surgical procedures (dieresis, hemostasis, resection and synthesis) have been described for two centuries and, together with the concepts of asepsis, must be systematically taught for the adequate training of the physician[2]. Classically, these operations were taught in classes of surgical technique with the use of live animals, since this was the method that most resembled the human body, besides the initial cost is low and presents greater similarity with the human tissues. [3] During the classes the models were used in the acquisition of knowledge and development of skills in surgery, which comprise the matrices of medical education. However, in this process, the animals used were subjected to suffering and deliberate sacrifice was often necessary[2,3].

But even with the inherent injury that the animal used in the procedures has, it is undeniable that this model is the one that most resembles the human model being, then, a great medium for the learning, especially in the development of abilities. However, a great debate exists on this subject and questions the real need to cause damage to the animal for the purpose of teaching alone[1].

However, with the growing bioethical debate, the institutions that used live animals during graduation were instructed to discontinue use, on the grounds that the animals submitted to the experiments were exposed to suffering and the real efficiency of this teaching method in the face of technical-scientific advancement[7]. Moreover, many students did not accept to attend classes with live animals, because they affirmed that they could not endure the suffering inflicted on healthy animals. Thus, although the use of animals in medical research has been successful in many therapeutic interventions, side effects can be observed[1,2].

In this context, educational institutions had to find new ways to transmit the content to the students.[7] Thus, the development of means capable of replacing the animal model in the teaching of the operative technique is fundamental so that teaching to the academics is not out of date and incomplete. Models that present a reality like that of the animal model, but that respect the bioethical principles required in the present time are needed[4]. Thus, the objective of this study is to carry out a review in the current literature on the alternative methods to the alive animal model for the teaching of the technique undergraduate course in medicine.

METHODS

A literature review was carried out in scientific articles published on the SciELO, PubMed and BIREME platforms using the following descriptors, in combination: Medical education; simulator training; surgical models; structural models; printing in 3D. The articles were searched between September 2017 and September 2018. Inclusion criteria were studies published in the last 15 years, the full text of which was available in Portuguese or English. Articles written in languages other than English or Portuguese, those whose title or abstract did not fit the proposed theme, were excluded, as well as studies that approached said models in contexts other than medical graduation or residency.

RESULTS

At the end, 20 studies were included to integrate this review article. Table 1 shows the distribution by authorship, country of origin, year of publication, title, journal and database of selected studies. Of the articles selected 9 were taken from Pubmed, 9 from Google Scholar and 2 from SciELO.

The focus of all articles selected was the need to develop alternative methods that would replace the animal model with the quality of teaching surgical technique. The articles propose substitutive models that include synthetic materials, chemical preservation of corpse, three-dimensional models (3D), to virtual models.

In the following topics will be approached the substitutive methods to the animal model, listing their main characteristics and applications, as well as bioethical and social context that permeates the theme, according to the studies surveyed.

Table 1. Selected studies according to authorship, title, journal and database

Reference	Title	Journal	Database		
			Pubmed	SciELO	*Google Acad.*
Campelo et al., 2016. Brazil	Projeto de ensino: modelo suíno de baixo custo para treinamento de drenagem torácica	Rev Col Bras Cir.		1	
Bastos et al., 2016. Brazil	Proposal of a synthetic ethylene-vinyl acetate bench model for surgical foundations learning	Acta Cir Bras.		1	
Coelho et al., 2015. Brazil	New anatomical simulator for pediatric neuroendoscopic practice. child's nervous System	Surgery.	1		
Kalvach et al., 2016. Czech Rep.	Existing laparoscopic simulators and their benefit for the surgeon	Rozhl Chir.	1		
Moura Júnior et al., 2015. Brazil	Modelo acadêmico de ensino teórico-prático em vídeo cirurgia por meio de novo simulador real de cavidade abdominal	Univ Federal do Ceará			1
Harenberg et al., 2016. US	Can multiple object tracking predict laparoscopic surgical skills?	J Surg Educ.			1
Glassman et al., 2016. US	Effect of playing vídeo games on laparoscopic skills performance: a systematic review	J Endourol.			1
Resende et al., 2012. Brazil	Simulador cirúrgico e realidade virtual no ensino de cirurgia de catarata	Res Bras Oftal.			1
Oliveira et al., 2016. Brazil	Simuladores para a Medicina	Pesq FAPESP			1
Nowinski et al., 2018. US	A 3D stereotactic atlas of the adult human skull base	Brain Inform.	1		
Park et al., 2018. South Corea	Use of a life-size three-dimensional-printed spine model for pedicle screw instrumentation training	J Orthop Surg Res.	1		
Garcia et al., 2018. Canada	3D printing materials and their use in medical education: a review of current technology and trends for the future	Simul Technol Enhac Learn.	1		
Badash et al., 2016. US	Innovations in surgery simulation: a review of past, current and future techniques	Ann Transl Med.	1		
Denadai et al., 2012. Brazil	Training on synthetic ethylene-vinyl acetate bench model allows novice medical students to acquire suture skills	Acta Cir Bras.			1
Motta et al., 2018. Brazil	Treinamento de habilidades cirúrgicas para estudantes de medicina – papel da simulação.	Rev Med.			1
Xu et al., 2018. China	Real-time inextensible surgical thread simulation.	Int J Comput Assist Radiol Surg.	1		
McCannel et al. US	Continuous Curvilinear Capsulorhexis Training and Non-Rhexis Related Vitreous Loss: The Specificity of Virtual Reality Simulator Surgical Training	Trans Am Ophthalmol Soc.	1		
Alaker et al., 2016. UK	Virtual reality training in laparoscopic surgery: A systematic review & meta-analysis	Int J Surg.	1		
Guimarães et al., 2016. Brazil	Utilização de animais em pesquisas: breve revisão da legislação no Brasil	Rev Bioét.			1
Marques et al., 2003. Brazil	Importância do ensino de técnica operatória e cirurgia experimental no curso de medicina	UERJ			1
Inglez de Souza et al., 2015. Brazil	Bleeding simulation in embalmed cadavers: bridging the gap between simulation and live surgery	ALTEX.	1		
Onyije et al., 2012. Nigeria	Excruciating effect of formaldehyde exposure to students in gross anatomy dissection laboratory	Int J Occup Environ.	1		

Synthetic Model

The synthetic model consists of a piece made from ethylene vinyl acetate that allows the student to train incisions, of the various types of sutures, be they continuous or discontinuous, as well as making flaps. It is a material that presents consistency and resistance similar to those of human tissue, although it has a different coloration[5].

The studies suggested suggesting that the synthetic model as an artificial tissue presents some advantages over the traditionally used animal tissue. In it, there is no production of secretions or putrefaction due to colonization by microorganism, which has benefits in relation to logistics, contagion and storage. Also, there is no risk of contagion or transmission of infectious-contagious diseases[6]. This model provides the practicality of being reproducible, low cost and easy to acquire. These characteristics make this material an important option to be used as a complementary resource in a synthesis and reconstruction class[5,7].

Parts of animals slaughtered for food consumption purposes - "*in natura*"

After slaughtering animals (pigs, goats, rabbits and chickens) slaughtered in food stores, the musculoskeletal structure is generally used for food purposes, and the organs and body viscera are less commercially available, since they are less consumed by the population. Thus, we can use this material rejected by consumption with the objective of using it as raw material in classes of surgical technique[1,6].

Although considering the specificities of the anatomical aspects in this animal model, the fact that it does not have circulating body fluids and the impossibility of demonstrating hemostasis, it presents favorable factors regarding the low cost and the texture of the tissues, being possible to demonstrate strategies surgical procedures for resection and reconstruction[3]. By way of illustration, operative technique demonstrations are presented in Figures 1, 2, 3, performed on organs removed from animal structure.

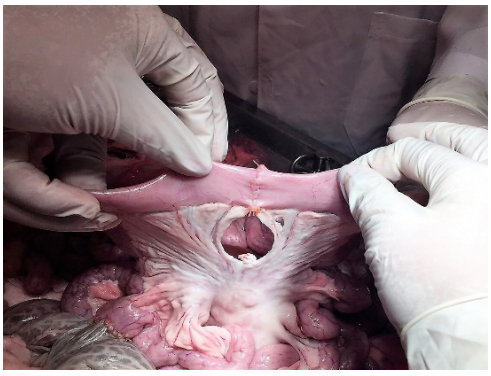

Figura 1 – Intestinal Anastomosis. (Own collection)

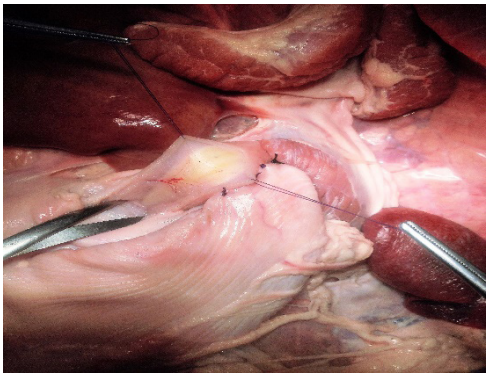

Figura 2 - HELLER Myotomy (Own collection)

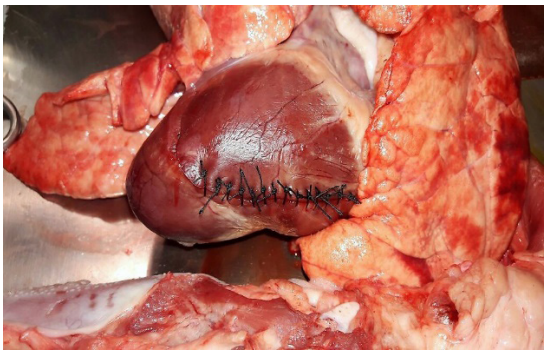

Figura 3 – Cardiac suture (Own collection)

Chemical preservation of corpses

The chemical preservation of cadavers is an interesting method to replace the use of the animal model in the Laboratories of Surgical Technique. The corpses used are animals that died in veterinary hospitals, shelters and zoonoses control centers. Removal of blood, scraping of the hair, washing of the intestinal contents and immersion of the part in a modified Larssen solution are necessary for preservation[7,8].

This solution aims to maintain characteristics such as color, tissue consistency and flexibility as similar as possible to those found in live animals, so that surgical teaching has the highest possible quality. It is composed of formalin, liquid glycerin, body hydrate, sodium sulfate, sodium bicarbonate, sodium chloride, distilled water. In addition to immersion, Larssen's solution is injected into the vascular bed. After this process, the pieces are placed in plastic bags and conditioned in cold rooms at - 20ºC. For its use it is necessary the gradual thawing in tanks with water 24 hours before the classroom[8,9].

After the preservation of the cadavers, the pieces present high fidelity for training and practical simulation in surgery and, as this is a chemically preserved animal model, individualities of the biological organism are maintained, such as anatomical variations. This model aims to replace the use of live animals for learning purposes and allows the acquisition of the proficiency necessary for the surgical practice.

3D models created by printers

Three-dimensional (3D) printers are devices that can print polymers for any type of object, including custom medical designs. They combine nine different polymers to produce the bio model with shape, texture, flexibility, consistency and coloration very close to the human. From this combination of polymers, differentiation of tissues such as skin, subcutaneous tissue, bones and the various organs takes place[10]. And three-dimensional images are produced by means of tomography and magnetic resonance information, which portray with great reliability the anatomical elements of the human being[11,12] .

The bio models are used in medical schools and other areas of health both for the disciplines of Anatomy, replacing the preserved human cadavers, as in the Surgical Technique Discipline, where it is used instead of the living animal model. The 3D printers present great potential in development of use since they present greater similarities with the alive human tissue when compared to the formolized cadavers. In addition, this material has great utility in training in complex operations, since the anatomical reality may present superior quality to that of the animal model[12,13].

Surgical Simulators

The simulation is the invention of the American engineer Edwin A. Link, creator of the first flight simulator, the "Link Trainer". In the medical field, the Norwegian Asmund Laerdal, in 1960, developed a simulator for cardiorespiratory resuscitation. Since then, several other high-tech models have been created for simulation in health training. For, just as aircraft drivers are required for a certain number of hours using virtual simulators, an accessible, safe, controlled and standardized place before piloting aircraft; today, more and more surgical simulators have been used both for the development of academic abilities, but mainly as a tool to increase the learning curve of physicians in surgical specialization[13].

In some universities there is the Laboratory of Surgical Skills, an environment of training and teaching that promotes realistic simulation of the spaces of a surgical center. In this place, with the use of the surgical simulator, the student can learn and train with the execution of the proposed task, being able to err, correct and repeat until correct. From the use of the simulators, the environmental impact can be minimized since the live animal model is replaced by the simulated model[13].

In the field of training of Surgery Residents, virtual surgery simulators are already well established, especially in ophthalmology, whose surgeries are extremely delicate, and minimal technical failures are not tolerated, as these may cause irreversible sequelae. Thus, the German simulator Eyesi is used in educational institutions in North America and Europe for training residents of cataract surgery with phacoemulsification prior to the commencement of surgical activities in patients and in real eyes. This training reduces time, increases efficiency in surgeries performed by residents, and provides a more agile learning curve with fewer complications[14].

The device consists of a system with binocular microscope mounted on a table with artificial head and eye coupled to the computer, pedal of the microscope and phacoemulsifier, faithfully reproducing the surgical equipment. This, in addition, has evaluation criteria of the student's performance with immediate feedback and sequence of exercises with increasing degrees of difficulty. In the surgeries of the digestive apparatus, especially with the advent of laparoscopic and robotic surgeries, the surgeon is required to have advanced techniques and abilities since laparoscopy times are of a very high complexity. In this regard, the development of simulators is fundamental for the resident to acquire these skills with efficiency[14,16].

A wide variety of simulators are available, each offering different features for performing the surgical procedure. Some offer manual dexterity, while others lack tactile feedback, but provide excellent virtual reality images and ease to provide better ergonomics[13]. Recently, a simulation device has been proposed in surgery that uses smartphone as an imaging source. The smartphone is coupled to a black hexagonal wooden box that features portals for the introduction of laparoscopic instruments. Thus, several activities are developed to acquire skills in laparoscopy. This device has a low manufacturing cost since it uses a smartphone for imaging instead of laparoscopic optics[18].

The abdominal cavity simulators, shown in Figures 4 and 5 as an illustration, are fiberglass structures consisting of a manikin simulating a human trunk with a thoracic and abdominal cavity, anteroposterior depth suitable for the operative movements, with a corresponding space to the one created by the pneumoperitoneum, at the same depth of the abdominal structures. According to the selected articles, this instrument is an option for undergraduate surgical teaching presenting as an important means for acquiring video laparoscopy abilities, however this medium still has low similarity with the animal model in terms of texture and anatomical characteristics[11,15].

Figure 4 – Laparoscopic abdominal cavity simulator. (Own collection)

Figure 5 – Laparoscopic suture training in abdominal cavity simulator. (Own collection)

DISCUSSION

According to the studies surveyed, the main alternative to teaching was the adoption of parts and organs of animals previously slaughtered, but which, because they were removed from the animal organism, present significant distortions. Thus, certain impairments in student learning are undeniable, especially regarding the anatomical reality, in the control of bleeding, hemostasis and organic reconstruction methods. Thus, in order to maintain excellence in the quality of teaching of surgical technique, it is important to adopt new means that sup- port or even, perhaps, overcome the deficiencies left in place of the living animal model[1,2].

Among the means that can replace the animal model, surgical simulators have been the most studied. In this review, 8 articles deal with the types of simulators, the characteristics of this teaching instrument, as well as the advantages and disadvantages presented. Another method that has a promising future is the 3 D model, presenting 5 studies with arguments in favor of this teaching tool. Both are still little used in the universe of Schools because of its high cost, the availability in series and the training of Instructors.

Because they are synthetic, 3D models have excellent logistic and storage capabilities. This, together with the anatomical fidelity obtained from computed tomography and magnetic resonance imaging, makes these models very promising and with great capacity to be widely used[9]. Surgical simulators are proposed instruments to reproduce a safe development environment and skills training that allow the practitioner to correct their mistakes. They are mainly active for the teaching of laparoscopic and robotic techniques. MIMIC® is a robotic surgery simulator widely used to accelerate the learning curve of surgeons and residents. In it are proposed several virtual exercises that facilitate the technical improvement of the surgeon in robotic surgery[15].

Existing models still present certain types of limitations, but with the advent of new technologies, evolutions of these models will certainly complement the teaching of surgery effectively[14].

The training in surgery, which begins in the academic and complete training in the specialization phase must be done with the acquisition of competence and skill development in models, so that in the evolution to the execution in humans, is already consolidated. Thus, even with the replacement of the traditional animal models that formed several generations of surgeons, it is necessary to adopt and apply the substitutive models for the safe training of the new generations of surgeons and surgeons[4].

This study addressed a topic of extreme relevance for the academic environment, given the need to incorporate these instruments in the graduation environment in the near future. In addition, the subject is current from a social and bioethical point of view and requires discussion in order to identify the best cost-benefit for the appropriate teaching of surgical technique with respect to animal rights. A search was made for current articles from several countries that contemplate the proposed theme in order to raise the current literature on the subject and to summarize what has been published in recent years.

However, the present study was not able to exhaust the literature on the subject, mainly due to difficulties with access to the full texts of some journals. Future studies could raise more widely other types of publication, such as theses and dissertations, in order to make the results more likely to be generalized.

CONCLUSION

We can conclude that the teaching of the Surgical Technique in Medical Schools undergoes transformations and, so that the quality of training of future physicians is not impaired, it is necessary to incorporate new learning instruments that aim to supply the absence of living animal models.

REFERENCE

1. Guimarães M, Freire J, Menezes L. Utilização de animais em pesquisas: breve revisão da legislação no Brasil. Rev Bioét. 2016;24(2):217-24. Disponível em: http://www.scielo.br/pdf/bioet/v24n2/1983-8034-bioet-24-2-0217.pdf.
2. Campelo F, Netto A, Sommer, C. Projeto de ensino: modelo suíno de baixo custo para treinamento de drenagem torácica. Rev Col Bras Cir. 2016;43(1):60-3. Disponível em: http://www.scielo.br/pdf/rcbc/v43n1/pt_0100-6991-rcbc-43-01-00060.pdf.
3. Matera, JM. Método de ensino substitutivo na Disciplina de Técnica Cirúrgica. In: Tréz TA, organizador. Instrumento animal: o uso prejudicial de animais no ensino superior. Bauru, SP: Canal 6; 2008. p.126.
4. Marques R. Importância do ensino de técnica operatória e cirurgia experimental no curso de medicina. Rev HUPE (Hosp Univ Pedro Ernesto, UERJ). 2003;2(1):34-5. Disponível em: http://revista.hupe.uerj.br/detalhe_artigo.asp?id=274.
5. Bastos E, Pigozzi D. Proposal of a synthetic ethylene-vinyl acetate bench model for surgical foundations learning. Acta Cir Bras. 2011;26(2):149. Disponível em: http://www.scielo.br/pdf/acb/v26n2/v26n2a14.pdf.
6. Denadai R, Saad-Hussne R, Oshiiwa M. Training on synthetic ethylene-vinyl acetate bench model allows novice medical students to acquire suture skills. Acta Cir Bras. 2012;27(3):271. http://dx.doi.org/10.1590/S0102-86502012000300012.
7. Motta E, Baracat E. Treinamento de habilidades cirúrgicas para estudantes de medicina – papel da simulação. Rev Med (São Paulo). 2018;97(1):18-23 http://orcid.org/0000-0001-5864-8801.
8. Inglez de Souza MC, Matera JM. Bleeding simulation in embalmed cadavers: bridging the gap between simulation and live surgery. ALTEX. 2015;32(1):59-63. doi: 10.14573/altex.1407311.
9. Onyije FM, Avwioro OG. Excruciating effect of formaldehyde exposure to students in gross anatomy dissection laboratory. Int J Occup Environ Med. 2012;3(2):92-5. Available from: http://www.theijoem.com/ijoem/index.php/ijoem/article/view/125/272.
10. Otoch J, Pereira P, Ussam E, Zanato A. Alternativas ao uso de animais no ensino de técnica cirúrgica. RESBCAL (São Paulo). 2012;1(1):33-40. Disponível em: http://revistas.bvs-vet.org.br/resbcal/article/view/4/1475.
11. Martelli N, Serrano C, Pineau J, Prognon P, Borget I, et al. Advantages and disadvantages of 3-dimensional printing in surgery: a systematic review. Surgery. 2016;159(6):1485-500. doi: 10.1016/j.surg.2015.12.017.
12. Coelho G, Zymberg S, Lyra M, Zanon N, Warf B, et al. New anatomical simulator for pediatric neuroendoscopic practice. Childs Nerv Syst. 2015;31(2):213-9. doi: 10.1007/s00381-014-2538-9.
13. Oliveira, M. Simuladores para a medicina. Técnologia e Engenharia Biomédica. Pesq FAPESP. 2016;247:62-5. Disponível em:http://revistapesquisa.fapesp.br/wp-content/uploads/2016/09/062-065_Modelos-médicos_247.pdf?f46fde.
14. Ferreira F. Modelo de ensino por meio de simulador de cavidade abdominal para progressão de habilidades em endossuturas videolaparoscópicas [dissertação]. Fortaleza: Centro Universitário Unichristus; 2016. Disponível em: https://unichristus.edu.br/wp-content/uploads/2017/06/MODELO-DE-ENSINO-POR-MEIO-DE-SIMULADOR-DE-CAVIDADE-ABDOMINAL-PARA-PROGRESSA%CC%83O-DE-HABILIDADES-EM-ENDOSSUTURAS-VIDEOLAPAROSCO%CC%81PICAS.pdf.
15. Resende F, Bisol RAR, Bisol T, Rezende FA. Simulador cirúrgico e realidade virtual no ensino de cirurgia de catarata. Rev Bras Oftalmol. 2012;71(3):147-8. http://dx.doi.org/10.1590/S0034-72802012000300001.
16. Harenberg S, Mccaffrey R, Butz M, Post D, Howlett J, Dorsch KD, et al. Can multiple object tracking predict laparoscopic surgical skills? J Surg Educ. 2016;73(3):386-90. https://doi.org/10.1016/j.jsurg.2015.11.013.
17. Glassman D, Yiasemidou M, Ishii H, Somani BK, Ahmed K, Biyani CS. Effect of playing vídeo games on laparoscopic skills performance: a systematic review. J Endourol. 2016;30(2):146-52. doi: 10.1089/end.2015.0425.
18. Moura Júnior LG. Modelo acadêmico de ensino teórico-prático em vídeo cirurgia por meio de novo simulador real de cavidade abdominal [dissertação]. Fortaleza: Universidade Federal do Ceará; 2015. Disponível em: http://www.repositorio.ufc.br/bitstream/riufc/15469/1/2015_tese_lgmourajunior.pdf.
19. Kalvach J, Ryska O, Ryska M. [Existing laparoscopic simulators and their benefit for the surgeon]. Rozhl Chir. 2016;95(1):4-12. Disponível em: https://www.ncbi.nlm.nih.gov/pubmed/26982186.
20. Nowinski W, Thaung T. A 3D stereotactic atlas of the adult human skull base. Brain Inform. 2018;5(2):1. doi: 10.1186/s40708-018-0082-1.
21. Park HJ, Wang C, Choi KH, Kim HN. Use of a life-size three-dimensional-printed spine model for pedicle screw instrumentation training. J Orthop Surg Res. 2018;13(1):86.

doi: 10.1186/s13018-018-0788-z.

22. Garcia J, Yang Z, Mongrain R, Leask RL, Lachapelle K. 3D printing materials and their use in medical education: a review of current technology and trends for the future. BMJ Simul Technol Enhanc Learn. 2018;4(1):27-40. doi: 10.1136/bmjstel-2017-000234.

23. Badash I, Burtt K, Solorzano CA, Carey JN. Innovations in surgery simulation: a review of past, current and future techniques. Ann Transl Med. 2016;4(23):453. doi: 10.21037/atm.2016.12.24.

24. Xu L, Liu Q. Real-time inextensible surgical thread simulation. Int J Comput Assist Radiol Surg. 2018;13(7):1019-35. doi: 10.1007/s11548-018-1739-1.

25. McCannel CA. Continuous curvilinear capsulorhexis training and non-rhexis related vitreous loss: the specificity of virtual reality simulator surgical training (an American Ophthalmological Society Thesis). Trans Am Ophthalmol Soc. 2017;115:T2. Available from: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5598788/.

26. Alaker M, Wynn GR, Arulampalam T. Virtual reality training in laparoscopic surgery: a systematic review & meta-analysis. Int J Surg. 2016;29:85-94. doi: 10.1016/j.ijsu.2016.03.034.

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