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Original Article

Chest tube simulator: development of low-cost model for training of physicians and medical students.

Simulador de dreno de tórax: desenvolvimento de modelo de baixo custo para capacitação de médicos e estudantes de medicina

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ABSTRACT

Objective: by using a 3D printer, to create a low-cost human chest cavity simulator that allows the reproduction of the closed chest drainage technique (CCD), comparing its effectiveness with that of the animal model. **Methods:** it was made a 3D printing of the bony framework of a human thorax from a chest computerized tomography scan. After printing the ribs, we performed tests with several materials that contributed to form the simulation of the thoracic cavity and pleura. An experimental, randomized, and controlled study, comparing the efficacy of the simulator to the efficacy of the animal model, was then carried out in the teaching of CCD technique for medical students, who were divided into two groups: animal model group and simulator model group, that trained CCD technique in animals and in the simulator model, respectively. **Results:** the chest reconstruction required anatomical knowledge for tomography analysis and for faithful 3D surface editing. There was no significant difference in the safety of performing the procedure in both groups (7.61 *vs*. 7.73; p=0.398). A higher score was observed in the simulator model group for "use as didactic material" and "learning of the chest drainage technique", when

compared to the animal model group ($p<0.05$). **Conclusion:** the final cost for producing the model was lower than that of a commercial simulator, what demonstrates the feasibility of using 3D printing for this purpose. In addition, the developed simulator was shown to be equivalent to the animal model in relation to the simulation of the drainage technique for practical learning, and there was preference for the simulator model as didactic material.
Keywords: Simulation. Models, Animal. Simulation Training. Training. Education, Medical. Drainage. Chest Tubes.

INTRODUCTION

Simulation consists of a tool that aims to reproduce, interactively and safely, aspects of real life[1,2]. In the health area, simulation is seen as an effective form of teaching, which improves patient and safety care, since the individual undergoing training — student or physician — goes through experiences very close to those of real life and consistent with decision-making in daily medical practice[1]. Simulation in the medical field can also provide the ability to recognize limitations and technical failures in procedures performed by health professionals. A well-conducted simulation program can create a favorable scenario in which activities become predictable, standardized, secure, and reproducible[3].

Simulators can be classified in different ways, ranging from computerized systems, dolls that play the role of patients, environments that simulate work situations, and even real people playing roles following a previously elaborated script. Another important aspect is the fidelity of the simulator. Here, "fidelity" is understood as the simulator's ability to approach the aspect and activities of the system to be simulated in real life[2]. Simple simulators can be highly effective when used to simulate cognitive tasks and review procedure steps. On the other hand, more complex simulators are needed to train and develop fine motor coordination skills.

However, one of the major problems and limitations that simulation centers present is the cost of most equipment, mannequins, partial models used, instructors, and maintenance[1-8]. Nevertheless, it is fully possible to develop low-cost simulators that prioritize the learning of tasks and routines in which repetitive practice is more important[1]. For simulations involving teams, detailed environments, high-tech mannequins, high-value softwares, integrated simulators, instructors, and real patients, the cost will be higher, but there will be the development of more complex simulations, so as to fit the specific purpose of each station[1,2,4].

The use of porcine rib hemithorax for training of the chest drain insertion technique by physicians and Brazilian medical students has already been described, with a high anatomical correlation between the porcine ribs and the human thorax[9]. The main advantage of the method is its low cost and easy obtainment of the material, since animal segments are relatively easier to acquire than a complete corpse. However, the model also presents limitations: because it is biological and perishable material, it cannot be reused and requires cooling care, so that the material does not deteriorate and the work does not become unfeasible. In addition, it is necessary that the skin and the subcutaneous tissue are intact and with optimum consistency and thickness, and, although the porcine rib is relatively easy to find in conventional supermarkets, the “ideal material”, under the mentioned conditions, is not.

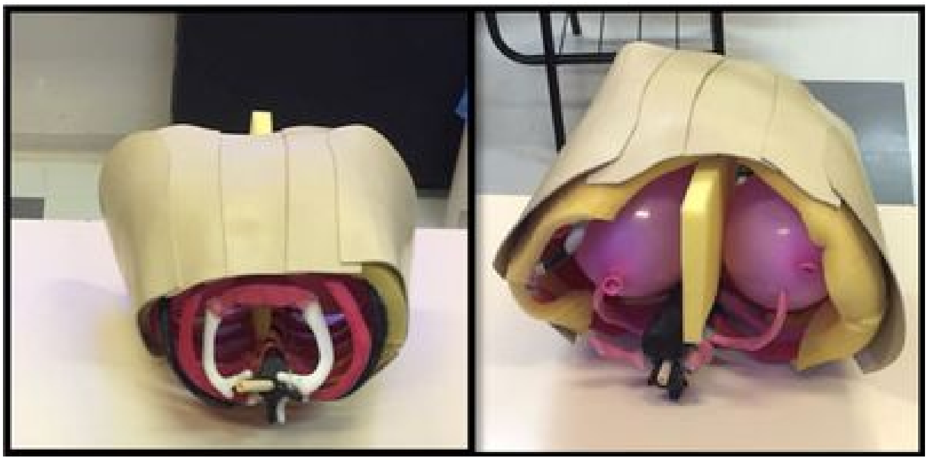
The objective of this work was to create a low-cost simulator using 3D printing, with anatomical conditions similar to a segment of the human thoracic cavity, in order to reproduce the closed chest drainage technique and apply the model developed in the training of medical students to evaluate its effectiveness and the satisfaction of the participants in relation to the simulator model compared to the animal model.

METHODS

An experimental, randomized, and controlled study was carried out through the development of a 3D printing model that allowed the simulated training of the closed chest drainage procedure for medical students at the emergency room of Hospital do Trabalhador, Curitiba, Parana, Brazil. A 3D printing of the bony framework of a human thorax was made using a chest tomography, without the need of a funder and through a partnership with Federal Technological University of Parana (UTFPR) with a total cost of approximately 133 dollars (Figure 1). After printing the ribs, tests were performed with various materials that contributed to form the simulation of the thoracic cavity and pleura (Figure 2).

Figure 1. 3D printing of a thorax.

Figure 2. Chest drain simulator model (SIM drain).



After completion, this model was used for the training of medical students in internship period at the emergency room of Hospital do Trabalhador. The academics, from the fifth to the eighth period, were invited to participate in the research on a voluntary basis. They were students from the five medical schools of Curitiba: Federal University of Parana (UFPR), Universidade Positivo (UP), Pontifical Catholic University of Parana (PUCPR), Evangelical Faculty of Parana (FEPAR), and Faculdades Pequeno Príncipe (FPP). A brief lecture was presented, exposing the chest drainage technique with the visual aid of a video. After this first part, the students answered part of the questionnaire evaluating the technique of the model. They answered questions about their safety in performing chest drainages after the presentation of its theoretical content. These technical questions were taken from a checklist of the chest drainage procedure developed by professors of the Training and Simulation discipline at Federal University of Parana.

The students were randomly divided into two groups: AMG, animal model group, the traditional simulation model, which performed drainage in the porcine model (porcine ribs), and SMG, simulator model group, which performed drainage in the simulator model developed by the authors.

After the practical activity, the students answered the questionnaire composed of two parts. The first part was about the students' experience in simulation and their safety in performing chest drainages in patients after the practical activity with the simulator. The second part was related to the content of the research. The students answered questions about the importance of this procedure in the undergraduation program, as well as if the model was useful as didactic material and allowed the learning of the technique, if they would like to use other simulators developed with the same concept, if the practical activity was adequate, and if the learning of the procedure was appropriate. All questions in the questionnaire should be answered through a scale ranging from 0 to 10. At the end, the academics answered questions to identify the sample, such as age, gender, university, and period. They had space to write comments and suggestions.

The results obtained were tabulated by Microsoft Excel. The normal distribution variables were described using mean and standard deviation. Epidemiological data were calculated with simple statistical percentages. The continuous variables were analyzed using Student's t-test. The rejection level of the null hypothesis was set at 5%. The present study was approved by Research Ethics Committee Involving Human Beings/Secretary of Health of Parana State under the number 2199465.

RESULTS

A total of 49 medical students participated in this study. The mean age was of 22.4 years and 30 students (61.2%) were female. Only 15 academics (30.6%) stated that they did not have experience with simulators. Twenty-three (46.9%) were submitted to the practical activity with the animal model (porcine ribs) and 26 (53%) with the simulator model, developed by the researchers.

After the theoretical presentation on the chest drainage technique and the video showing the procedure, the 49 medical students answered this question: "How safe would you feel to perform the procedure on a patient?". The average of the grades was 5.44 (in the AMG, the average was 5.47; in the SMG, 5.42 — p=0.460). After the practical activity, the 49 academics were asked to answer the same question, and, on this occasion, the average of the grades was 7.67 (in the AMG, the average was 7.60; in the SMG, 7.73 — p=0.398). The score of the participants of this study (n=49) ranged from 5.44 to 7.67 (p<0.001). In the AMG, it ranged from 5.47 to 7.60, reflecting an increase of 38.9% (p<0.0001). In the SMG, the score ranged from 5.42 to 7.73, reflecting an increase of 42.6% (p<0.0001) (Table 1).

Table 1. Safety of performing a chest drainage procedure on a patient.

	Total (n=49)	AMG* (n=23)	SMG** (n=26)	p
After theoretical presentation	5.44 (±1.93)	5.47 (±2.04)	5.42 (±1.87)	0.460
After practical training	7.67 (±1.63)	7.61 (±1.43)	7.73 (±1.82)	0.398

*AMG: animal model group; **SMG: simulator model group.

In relation to the experience in the simulation, the students were asked to punctuate some items about the safety they would have to perform the following techniques in a patient: approximately 1.5cm skin incision, divulsion of the planes with penetration into the pleural cavity, introduction of the index finger into the pleural orifice, drain insertion (posterosuperiorly) until the mark is reached. When comparing the average of the grades of the two groups after the practical activity, totals of 8.95 for the AMG and 9.11 for the SMG (p=0.335) were found for the first item evaluated; for the second item, 7.95 for the AMG and 8.57 for the SMG (p=0.146); for the third item, 8.69 for the AMG and 9.07 for the SMG (p=0.194); and, for the fourth item, 8.26 for the AMG and 8.73 for the SMG (p=0.143) (Table 2).

Table 2. Technical experience undergone through practical training.

	Total (n=49)	AMG* (n=23)	SMG** (n=26)	p
Approximately 1.5cm skin incision	9.04 (±1.29)	8.95 (±1.49)	9.11 (±1.17)	0.335
Divulsion of the planes with penetration into the pleural cavity	8.28 (±2.04)	7.95 (±2.34)	8.57 (±1.72)	0.146
Introduction of the index finger into the pleural orifice	8.89 (±1.53)	8.69 (±1.89)	9.07 (±1.12)	0.194
Drain insertion (posterosuperiorly) until the mark is reached	8.51 (±1.52)	8.26 (±1.81)	8.73 (±1.22)	0.143

*AMG: animal model group; **SMG: simulator model group.

The range of the average of the grades (in percentage) after the theoretical presentation and the practical activity was described in Table 3.

Table 3. Range of the score, before and after the practical activity.

	After theoretical presentation		After practical activity		Range (%)	
	AMG*	SMG**	AMG*	SMG**	AMG*	SMG**
Approximately 1.5cm skin incision	8.21	8.03	8.95	9.11	9	13.4
Divulsion of the planes with penetration into the pleural cavity	6.82	6.84	7.95	8.57	16.5	25.2
Introduction of the index finger into the pleural orifice	7.34	8.34	8.69	9.07	18.3	8.7
Drain insertion (posterosuperiorly) until the mark is reached	5.91	6.23	8.26	8.73	39.7	40.1

*AMG: animal model group; **SMG: simulator model group.

In both groups, there was an increase in the average of the grades in all evaluated items of the checklist. Regarding the content, the participants considered of great relevance the practice of the chest drainage procedure for medical undergraduate students, attributing an average score of 9.81. When the SMG students were asked if they would like to use other simulators developed with the same concept, the average of the grades was 9.69. When asked whether the model was useful as didactic material for the undergraduation program, the average of the grades was 8 for the AMG and 8.88 (p=0.016) for the SMG. When asked if the model allowed the learning of the chest drainage techniques, the average of the grades was 8.17 for the AMG; 8.88 for the SMG (p=0.022) (Table 4).

Table 4. Didactic content

	Total (n=49)	AMG* (n=23)	SMG** (n=26)	p
Was the model useful as didactic material for the undergraduation program?	8.46 (±1.45)	8.0 (±1.56)	8.88 (±1.24)	0.016***
Did the model allow the learning of the chest drainage techniques?	8.55 (±1.24)	8.17 (±1.26)	8.88 (±1.14)	0.022***
Was the practical activity adequate?	9.02 (±1.42)	8.91 (±1.78)	9.11 (±1.03)	0.312
Was the learning of the procedure adequate?	8.51 (±1.67)	8.30 (±1.89)	8.69 (±1.46)	0.211

*AMG: animal model group; **SMG: simulator model group; ***statistically significant result.

DISCUSSION

Medical education has been undergoing a paradigm shift, placing simulation as an effective tool to meet the new educational and social challenges of our time[10]. The high cost of simulators is still the main limitation of their use by universities in the teaching of medical students[11]. Thus, the role of the practical, effective, and low-cost simulator developed by the authors of the article is highlighted.

When questioned about the safety in performing the chest drainage procedure in a patient after the theoretical class, very similar scores were observed between the SMG and the AMG, what confirms the homogeneity of the groups in which they were separated.

By relating the scores the students gave to the same questioning after the theoretical presentation and after the practical activity, the results were statistically significant. There was an increase in the score for both the AMG and the SMG, what reveals that the practical activity has a superior benefit in developing confidence and safety to perform the procedure when compared to just theoretical presentation and illustrative videos, and, in this respect, both models that were used fulfilled the goal. Literature is extensive in stating that the observation-based learning model is debatable because it does not stimulate the student's total involvement and does not produce effective training. Thus, for skill acquisition, especially in the surgical and interventional procedure areas, sustained practice is necessary[12]. In addition, the use of some synthetic model is essential so that the student can gain confidence and, later, carry out clinical procedures on patients[13].

In the question about how secure they felt in performing the procedure after the practical activity with the simulator, the scores were also similar for both groups, and, although the SMG presented a greater difference between the pre- and post-practice grades, there was no statistic significance between them, revealing that the simulator model may not be superior to the traditional animal model in the learning gain of the students, but it is equivalent.

Nowadays, the "3 R's Program" is known and well-established. Its objective is of reducing, refining, and replacing the number of animals used in research and improving the conduction of the studies in order to reduce to the possible minimum the suffering and to increase the search for alternative methods that, in the end, replace the in vivo tests[14]. Thus, the use of the simulator is an excellent option for training, since, besides having the consistency similar to that of a real model, it does not allow the sacrifice of an animal model, in the initial phase of the academic learning[15].

For comparison between groups, the researchers chose the checklist steps that depended on the practice in a simulator model to be performed. They were the following: approximately 1.5cm skin incision, divulsion of the planes with penetration into the pleural cavity, introduction of the index finger into the pleural orifice, drain insertion (posterosuperiorly) until the mark is reached. The results showed that there was an increase in the average of the grades in all the evaluated steps of the checklist, reinforcing the fact that, after the practical training activity, the learning is greater.

There was no statistically significant difference in the average of the grades between the groups after the practical activity, what shows that the models are similar in relation to the objective of teaching the procedure for academics. However, it must be considered that the increase in the averages was higher for the SMG in three of the four evaluated parameters. It was also observed that the item called “drain insertion (posterosuperiorly) until the mark is reached” was the one which obtained the highest score increment after practical activity, in the AMG and SMG, with an increase of approximately 40% in both groups. This data is of great relevance for the teaching in medical schools, since it is known that one of the great difficulties of the apprentice doctor is the correct placement of the drain in the patient (posterosuperiorly) and that poor positioning can result in non-adequate functioning and complications[16,17].

Although the checklist item called “marking the drainage site” was not evaluated, it should be considered that only the simulator model can guide the student to fulfill this requirement, since it preserves the anatomical reference points of the human chest, unlike the animal model, in which a piece of porcine rib is used for the same purpose.

As didactic material, the simulator model was preferred by the students, with statistically significant difference. This can be explained by the students’ perception of being more comfortable using the simulator in relation to the animal model. The use of animals remains as a training alternative, but with increasing respect for ethical norms for their utilization and respecting their use for increasingly specific situations in which complexity is high[18]. The search for alternative resources to the use of animals leads to the ethical valorization in the educational environment, besides preserving the ethical, moral, psychological, and social integrity of the students[13]. In addition, the students stated that, for the learning of the chest drainage technique, the simulator model was also superior to the animal model, with statistically significant difference. This result was already expected, since satisfaction with simulation as a teaching method has been consistently proven[19]. The use of technological advancements for teaching is imperative, primarily for younger generations of medical students, and educational formats must adapt to learning styles and preferences[20].

As limitation to the study, we can mention the subjectivity of the evaluated items in the form of a questionnaire response (using a graduated scale), since the experience of each one with the simulation depends on several personal factors, such as previous experience with simulators, perception about the use of animals for teaching, and the student's personal experience in the offered practical activity.

With our work, we could conclude that the final cost for producing the model was lower than that of a commercial simulator, what demonstrates the feasibility of using 3D printing for this purpose. In addition, the developed simulator was shown to be equivalent to the animal model in relation to the simulation of the drainage technique for practical learning, and there was preference for the simulator model as didactic material.

RESUMO

Objetivo: criar, em impressora 3D, um simulador de baixo custo de caixa torácica humana que permita a reprodução da técnica de drenagem fechada de tórax (DFT) comparando sua eficácia com a do modelo animal. **Métodos**: foi realizada impressão 3D do arcabouço ósseo de um tórax humano a partir de uma tomografia de tórax. Após a impressão das costelas, foram realizados testes com diversos materiais que contribuíram para formar a simulação da caixa torácica e da pleura. Foi, então, realizado um estudo experimental, randomizado e controlado comparando sua eficácia ao modelo animal no ensino da DFT para estudantes de medicina, que foram divididos em dois grupos: Grupo Modelo Animal e Grupo Modelo Simulador, que treinaram DFT em animais e no modelo simulador, respectivamente. **Resultados**: a reconstrução do tórax exigiu o conhecimento anatômico para análise da tomografia e para edição fiel da superfície 3D. Não houve diferença significativa quanto à segurança de realizar o procedimento entre os grupos (7,61 *vs*. 7,73; $p=0,398$). Foi observada maior pontuação no grupo modelo simulador para uso como material didático e aprendizado da técnica de drenagem torácica quando comparado ao grupo modelo animal ($p<0,05$). **Conclusão**: o custo final para a confecção do modelo foi inferior ao de um simulador comercial, o que demonstra a viabilidade do uso da impressão 3D para esse fim. Além disso, o simulador desenvolvido se mostrou equivalente ao modelo animal quanto à simulação da técnica de drenagem para aprendizado prático e houve preferência pelo modelo simulador como material didático.

Descritores: Simulação. Modelos Animais. Treinamento por Simulação. Capacitação. Educação Médica. Drenagem. Tubos Torácicos.

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