Low-cost Synthetic Simulators in Teaching Plastic Surgery for Medical Students

Simuladores sintéticos de baixo custo no ensino de Cirurgia Plástica para estudantes de Medicina

Artur Diógenes Vasques Farias[1] Ivens Rafael Resplande de Sá[1] Leticia Libório Santos[1] Lucas Evangelista de Andrade[1] Lourrany Borges Costa[1,2]

[1] Universidade de Fortaleza, Curso de Medicina, Fortaleza, Ceará, Brazil
[2] Universidade Federal do Ceará, Postgraduate Program in Public Health, Fortaleza, Ceará, Brazil

Address for correspondence Lourrany Borges Costa, Universidade de Fortaleza, Curso de Medicina, Fortaleza, Ceará, Brasil (e-mail: lourranybc@unifor.br; lourranybc@gmail.com).

Rev Bras Cir Plást 2025;40:s00451809396.

Abstract

Introduction Realistic simulation in medical education allows for practical experience in complex clinical scenarios, promoting meaningful and safe learning. It is an essential strategy for teaching surgical skills, a critical area for newly graduated physicians.

Objective This study evaluated the effectiveness of low-cost synthetic models for teaching surgical skills to medical students at the Academic League of Plastic Surgery (LICIP) of the University of Fortaleza, Ceará, Brazil.

Method This descriptive cross-sectional study involved medical students participating in a surgical skill training course promoted by LICIP. The course included 40 hours of training, divided into virtual theoretical classes and practical classes with synthetic models. LICIP produced models with accessible materials and asked professors and surgeons to evaluate them. We assessed the opinions about the effectiveness of their use for teaching through a self-administered virtual questionnaire.

Results Among the 50 participants, 68% had never had contact with surgical simulators before. After theoretical classes alone, most assessed their knowledge of surgical techniques as insufficient. After practical training, 88% considered their knowledge high. All reported that practicing with models increased their interest in surgery.

Conclusion The use of low-cost simulators proved to be viable, economical, and effective for the surgical training of medical students, significantly improving knowledge retention, acquisition of practical skills, and confidence in performing surgical procedures.

Keywords

- ► high fidelity simulation training
- ► medical education
- ► plastic surgery
- ► plastic surgery procedures
- ► training courses

received
August 19, 2024
accepted
March 24, 2025

DOI https://doi.org/10.1055/s-0045-1809396.
ISSN 2177-1235.

Thieme Revinter Publicações Ltda., Rua Rego Freitas, 175, loja 1, República, São Paulo, SP, CEP 01220-010, Brazil

Resumo

Introdução A simulação realística em educação médica permite adquirir experiência prática em cenários clínicos complexos, promovendo um aprendizado significativo e seguro. É uma estratégia importante para o ensino de habilidades cirúrgicas, área crítica para médicos recém-formados.

Objetivo Avaliar a efetividade de modelos sintéticos de baixo custo na aprendizagem de habilidades cirúrgicas por estudantes de Medicina em ações realizadas pela Liga Acadêmica de Cirurgia Plástica (LICIP) da Universidade de Fortaleza, Ceará.

Método Trata-se de um estudo transversal descritivo, envolvendo estudantes de Medicina que participaram de um curso de treinamento de habilidades cirúrgicas promovido pela LICIP. O curso incluiu 40 horas de treinamento, divididas entre aulas teóricas virtuais e práticas com os modelos sintéticos. Os modelos foram produzidos pela Liga com materiais acessíveis e avaliados por professores e cirurgiões. A opinião sobre a efetividade de seu uso para a aprendizagem foi avaliada através de um questionário virtual autoaplicável.

Resultados Dos 50 participantes, 68% nunca haviam tido contato com simuladores cirúrgicos antes. Após as aulas teóricas somente, a maioria avaliou seu conhecimento sobre técnicas cirúrgicas como insuficiente. Após o treinamento prático, 88% avaliaram seus conhecimentos como altos. Todos relataram que a prática com modelos aumentou seu interesse por cirurgia.

Conclusão A utilização de simuladores de baixo custo mostrou-se viável, econômica e efetiva para o treinamento cirúrgico de estudantes de Medicina, melhorando significativamente a retenção de conhecimento, a aquisição de habilidades práticas e a confiança dos alunos em realizar procedimentos cirúrgicos.

Palavras-chave

- educação médica
- cirurgia plástica
- cursos de capacitação
- procedimentos de cirurgia plástica
- treinamento com simulação de alta fidelidade

Introduction

Educational methods involving high-fidelity simulations provide medical students with early experience in complex clinical topics, allowing them to develop skills essential to real-world work environments. Simulation allows practicing medical skills in a controlled environment, promoting meaningful learning that encourages reflection on one's practice. The use of simulators has been driven by trends in healthcare and education, such as increasing medical literacy, the significance of patient safety and quality of life for healthcare professionals, limitations on work hours, and the movement toward competency-based education.[1]

A particularly notable aspect is using simulation to teach surgical skills, a crucial area for new physicians. In 2014, the Association of American Medical Colleges (AAMC) introduced 13 professionally entrustable activities (EPAs) essential for all medical graduates entering residency. The measure answered the concerns of residency program directors, especially in Surgery, about the lack of preparation of recent graduates for the duties of a first-year resident.[2] The Brazilian National Curricular Guidelines also emphasize this aspect since surgical skills are paramount to train a generalist physician.[3]

Meaningful learning through simulation has been established in other high-risk professions, increasing safety and reducing risks. For a long time, simulation incorporation in medical education was underestimated for several reasons, including high costs, lack of rigorous evidence of its effectiveness, and resistance to change. Despite the undeniable value of training in real situations, its limitations include safety-related concerns. In addition, it is preferable to perform training in invasive surgical procedures in simulators, reducing the risk of medical errors and complications in actual procedures.[4,5]

During academic training, healthcare professionals often perform outpatient or surgical procedures with no prior training. The lack of economic resources and the high cost of medical practice training products resulted in the development of viable alternatives as low-cost teaching resources.[6,7]

Objective

This study aimed to evaluate the effectiveness of low-cost synthetic models in simulating surgical procedures and teaching surgical skills to medical students.

Methods

This prospective intervention study occurred at the University of Fortaleza (Unifor) with undergraduate medical students over 18 years old, of both genders, enrolled from the first to the last period of the course, from September 2023 to August 2024, participating in a surgical skill training course promoted by the institution's Academic League of Plastic Surgery (LICIP).

We recruited the participants through a public call with broad virtual dissemination of the research via e-mail, as a hidden list, and publication on social networks and electronic messages, containing the invitation, the electronic address with information about the study, an informed consent form, and an opinion questionnaire. Students under 18 years old, with suspended course enrollment, who did not agree to participate in the study or dropped out at some stage, and questionnaires with filling errors were excluded. We used a self-administered virtual questionnaire from the Google Forms online platform with 26 objective questions about the theoretical and practical surgical training classes using simulators and the content retention by the students. The students evaluated their content retention after a single theoretical class and after the class plus a simulated practice on a scale of 1 to 5 (1 = very poor; 2 = poor; 3 = indifferent; 4 = good; 5 = very good).

The training and the manufacturing of low-cost simulators occurred at the Experimental Biology Center (NUBEX) of Unifor. The course lasted 40 hours, including 20 hours of distance learning and 20 hours in person, divided into seven meetings lasting 2 hours each and 3 in-person meetings lasting 4 hours each. Remotely, students watched theoretical video classes recorded via the Google Scholar platform, and, in person, they practiced the surgical techniques discussed in the video classes using synthetic models with the help of monitors and professors. The release of each video class occurred 3 days before the corresponding practical class. The topics included basic Anesthesiology, fundamentals in surgery, Aesthetic Plastic Surgery - basics in rhinoplasty and labiaplasty, Reconstructive Plastic Surgery - basics in flap and reconstruction of the nipple-areola complex (NAC), liposuction and otoplasty, and basics in videolaparoscopy.

The low-cost simulators manufactured for practical training were the following:

Otoplasty Model

The base structure used a mannequin head covered with a uniform layer of foam 1 cm thick, fixed with hot glue, providing the shape and consistency necessary to simulate the anatomical characteristics of the ear region. Next, we applied a fabric mesh to the foam surface to represent the skin, giving the model a more realistic aesthetic appearance. In the ear region, we made two bilateral and symmetrical openings in the mesh, each measuring 6 cm in diameter, for the insertion and removal of the synthetic ears as this model was designed to be reusable, allowing the replacement of the synthetic ears after each suture practice using the Furnas and Mustardé surgical techniques. We produced two models and 80 pairs of interchangeable ears for training, allowing their replacement after each participant had performed the procedure. The total production cost of a model was approximately R$ 100.00 (►**Figure 1**).

Rhinoplasty Model

We used a plastic mask with hot glue applications as a bony framework for the face, including the nasal septum and the nasal bones. We did the cartilages with acetic silicone, using a handcrafted epoxy mold to reproduce the shape of the upper and lower lateral cartilages. We fixated the cartilages to the bony framework using suture threads, providing stability and realistic anatomy to the model. Acetic silicone allows repeated training without significant wear, facilitating the cartilage replacement with new molded parts as needed. We prepared three models, each with a total cost of approximately R$ 150.00 (►**Figure 2**).

NAC Reconstruction Model

We used a mannequin of the upper limb as a base and applied a 0.5 cm-thick foam layer. Additionally, we superimposed several layers of foam on the flanks and thorax, fixated with hot glue, to anatomically shape the body and simulate female characteristics. Next, we covered the model with mesh, providing a more aesthetic surface. In the breast region, on both sides, we left strategic spaces for foam disc insertion and removal with sutures. These discs had the same thickness and mesh coverage as the mannequin. We inserted the discs in the designated spaces on the model to allow repeated reconstruction performance after replacing the removed

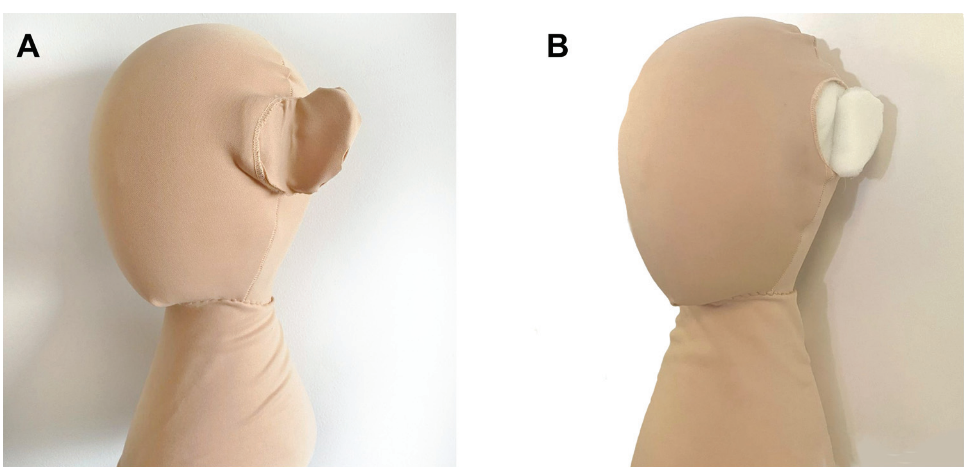

Fig. 1 Model for otoplasty training. Source: the authors.

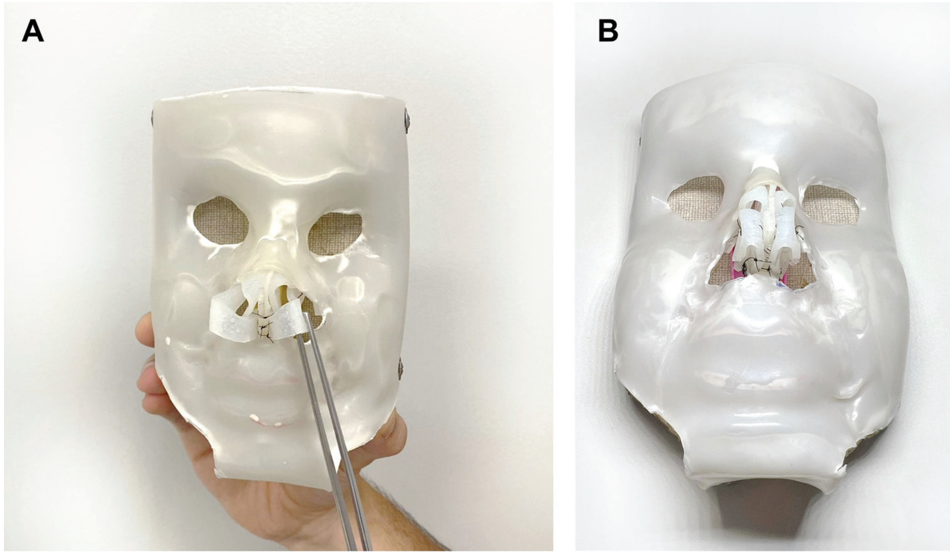

Fig. 2 Model for rhinoplasty training. Source: the authors.

discs with new ones after each practice. We made two models, each costing approximately R$ 170.00 (►**Figure 3**).

Labiaplasty Model

The labiaplasty model consisted of a fabric mannequin filled with foam representing a female pelvis in the lithotomy position. We made the labia majora individually from thicker fabric and molded them by sewing to fit snugly into the model's pelvis. The model allowed students to practice the labia majora reduction from the labiaplasty procedure and sutures. After suturing, it is easy to replace the labia majora alone, made from thicker, dark pink fabric. As such, it is possible to reuse the model, saving resources and allowing multiple students to practice the labiaplasty technique efficiently and realistically. We made two models, each costing approximately R$ 100.00 (►**Figure 4**).

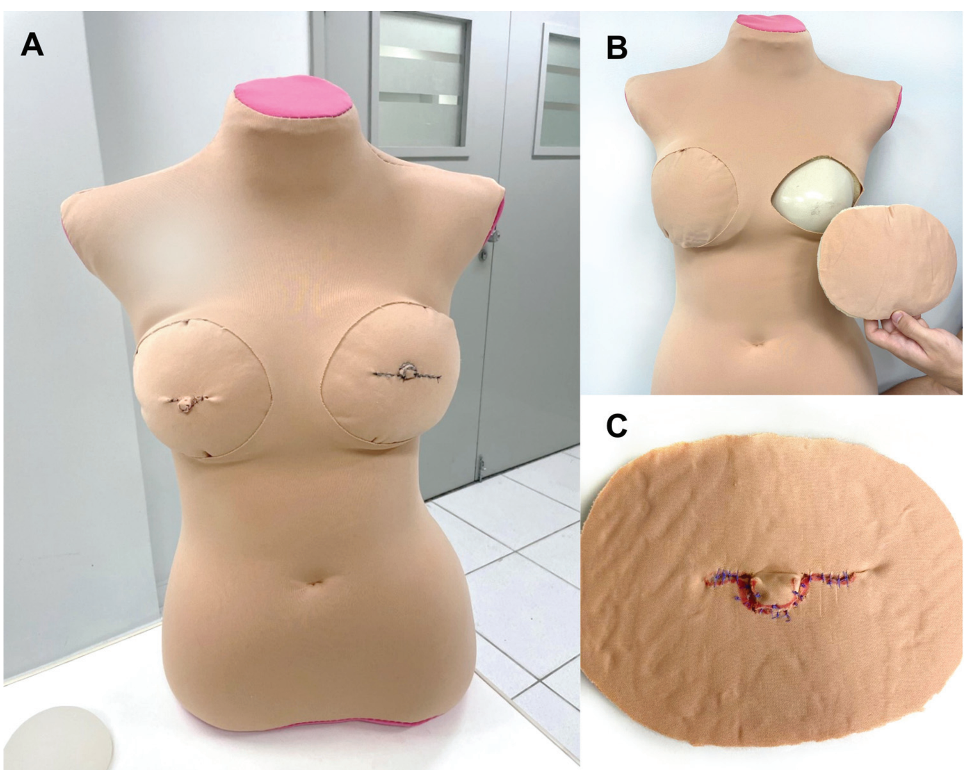

Fig. 3 (**A**). Model for nipple-areola complex (NAC) reconstruction. (**B**). Removable piece for performing the technique, reproducing a post-mastectomy breast. Piece replacement allows reusing the model. (**C**). Reproduction of the C-V flap technique for NAC reconstruction. Source: the authors.

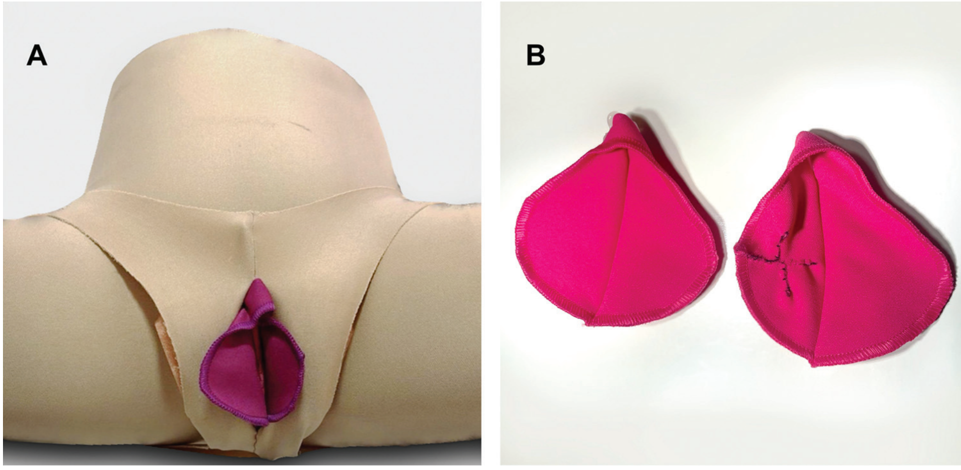

Fig. 4 (**A**). Model for labiaplasty with the possibility of replacing and reusing the labia minora after training. (**B**). Labia minora before (right) and after (left) training in the star resection technique. Source: the authors.

Liposuction Model

The liposuction model consisted of a mannequin body, a 0.5 cm wide sponge, 1.5 m of beige mesh fabric, 0.5 m of light pink fabric, a zipper, and micro-pearl Styrofoam. We used a mannequin thorax wrapped in a layer of a 0.5 cm sponge, covered with fabrics sewn together to form the shape of a bust, simulating a human body. We sew another fabric layer on top of it, in the abdominal region, delimiting a virtual cavity. We filled this cavity with micro-pearl Styrofoam and closed it at the bottom with a zipper. The purpose of this double layer is to absorb the Styrofoam with a cannula attached to a homemade vacuum cleaner, simulating the removal of body fat. We sew the tissue in the umbilical region separately to allow reuse after the suprapubic incision and put a small layer of replaceable foam. Other plastic surgeons and league members tested the model, proving its effectiveness as an innovative alternative for the surgical practice of liposuction. We manufactured one model at a total cost of approximately R$ 200.00 (►**Figure 5**).

Fig. 5 Model for liposuction training. Source: the authors.

For questionnaire response analysis, we expressed categorical data as absolute counts and percentages. First, we assessed continuous data for normality using the Shapiro-Wilk test. We expressed parametric data as mean $\pm$ standard deviation (SD), and nonparametric data as median and interquartile range (IQR). Comparisons between two independent groups used the Student's *t*-test for parametric data and the Wilcoxon test for nonparametric data. The hypothesis was that retention was higher after simulated training compared with theoretical training alone. Statistical significance was set at $p < 0.05$. We performed the analyses using Jamovi software.[8]

The Unifor Ethics Committee approved the project considering the ethical and legal precepts guiding research involving human beings per Resolution 466/12 from December 2012 of the Brazilian National Health Council (CAEE 73903623.6.0000.5052).

Results

Fifty students participated in the study, including 23 (46%) males and 27 (54%) females. The median age of the participants was 19.5 years (minimum, 17, and maximum, 39; IQR, 2). All participants were enrolled in the Medicine course, including four (8%) in the 1st semester, 17 (34%) in the 2nd semester, 17 (34%) in the 3rd semester, nine (18%) in the 4th semester, one (2%) in the 5th semester, one (2%) in the 6th semester, and one (2%) in the 8th semester.

Table 1 Response pattern to the questionnaire on knowledge retention of surgical techniques (range 1 to 5) after theoretical or theoretical and practical classes with a synthetic model. Fortaleza, Brazil, 2024

	After attending the theoretical class on the surgical technique alone			After attending the theoretical class and practicing with a synthetic model				
	Mean (SD)	95% CI	Median (IQR)	Mean (SD)	95% CI	Median (IQR)	W	*p*
Otoplasty	3.80 (0.67)	3.61 - 3.99	4 (0.75)	4.70 (0.64)	4.52 - 4.88	5 (0.0)	95[a]	<.001
Labiaplasty	3.80 (0.80)	3.57 - 4.03	4 (0.0)	4.74 (0.56)	4.58 - 4.90	5 (0.0)	78[b]	<.001
Rhinoplasty	3.80 (0.80)	3.57 - 4.03	4 (1.0)	4.62 (0.75)	4.41 - 4.83	5 (0.0)	78[d]	<.001
NAC reconstruction	3.86 (0.60)	3.69 - 4.03	4 (0.0)	4.74 (0.52)	4.59 - 4.89	5 (0.0)	64.5[b]	<.001
Liposuction	3.92 (0.69)	3.72 - 4.12	4 (0.0)	4.56 (0.73)	4.35 - 4.77	5 (1.0)	134[e]	<.001

Source: the authors. Abbreviations: CI, Confidence interval; IQR, interquartile range; NAC, nipple-areola complex; SD, standard deviation; W, Wilcoxon test.
[a] 8 tied value pairs.
[b] 10 tied value pairs.
[d] 12 tied value pairs.
[e] 11 tied value pairs.

Most participants ($n = 29$, 58%) responded that their main study method was attending theoretical classes and performing actual practices simulating the reality of the theoretical content. A minority answered that they only had theoretical classes or had classes and imagined actual situations.

Most participants ($n = 34$, 68%) had never had contact with a surgical simulator before participating in the LICIP course. Among those who responded that they had had contact before, the main simulators mentioned were a skin or arm model for suture training, a thoracic drainage simulator, and a paracentesis simulator. No student had previously contact with synthetic models for training in otoplasty, rhinoplasty, and liposuction. A single student knew of a model for NAC reconstruction surgery, and four were aware of a model for labiaplasty.

Approximately 76% ($n = 38$) of the students evaluated their knowledge of plastic surgery techniques as zero, 1, or 2 (on a scale where zero is equivalent to no knowledge and 5 is maximum knowledge) before the course.

After attending a single theoretical class on otoplasty, labiaplasty, rhinoplasty, NAC reconstruction, and liposuction, most students answered that they had good retention of the content learned, respectively 64% ($n = 32$), 62% ($n = 31$), 56% ($n = 28$), 68% ($n = 34$), 64% ($n = 32$). After performing practical training of each surgical technique on low-cost synthetic models, most students responded that learning retention was very good: 80% ($n = 40$) for otoplasty, 80% ($n = 40$) for labiaplasty, 76% ($n = 38$) for rhinoplasty, 78% ($n = 39$) for NAC reconstruction, and 70% ($n = 35$) for liposuction. After the practical sessions, 88% ($n = 44$) of the participants evaluated their knowledge as 4 or 5.

The frequencies of responses regarding content retention after theoretical class alone and after class plus simulated practice for all surgeries followed a non-normal distribution (Shapiro-Wilk test, $p < 0.01$). The median values of the responses after classes and practices were significantly higher (Wilcoxon test, $p < 0.001$) when compared with theoretical classes alone (►**Table 1**). Although mean values do not represent the behavior of the variables well, we decided to present them for potential comparisons with other studies. All respondents reported that the practice with synthetic models helped to awaken some interest in surgery and that they consider the use of low-cost surgical models to be relevant in the development of medical skills.

Discussion

This study evaluates the effectiveness of low-cost synthetic models in simulating surgical procedures and teaching surgical skills to medical students. The study involved 50 students using low-cost synthetic models to train in otoplasty, rhinoplasty, and liposuction. After the course, most participants rated their knowledge as high, and all reported that hands-on experience with synthetic models helped spark their interest in surgery.

In recent years, medical school has undergone significant changes, requiring adaptations in surgical skill teaching. The traditional teaching scenario also changed due to financial costs, cultural and social alterations, and new teaching-learning technologies.[5]

Over the years, it was realized that medical school graduates trained in surgical skills using the Halstedian model ("see one, do one, teach one") had no proper preparation for medical residency. An efficient and accessible method of teaching and assessing knowledge and skills that could be widely applied was needed. The solution was simulated training, which provides a safe environment for students to practice and learn before dealing with actual patients and scenarios.[9,10]

Simulation includes physical models, such as synthetic "dry lab" benches, cadaver and animal models, and virtual and augmented reality simulators. New simulator-based technologies are increasingly in use, with varying levels of realism. The American College of Surgeons, for instance, does not require animal training, using simulators for specialist accreditation.[7]

Low-fidelity simulators consist of static mannequins to train basic skills and do not interact with the trainee. In contrast, high-fidelity simulators are computer-controlled and adjust parameters according to the participant's performance; they are often expensive. Low-cost simulators are made with accessible materials and replicate the anatomy required for specific training.[11] Despite the differences between simulator types, the literature shows that training surgical skills on low-fidelity models is as effective as training on high-fidelity models.[9,12] These data corroborate the findings of our study.

The evaluation of the effectiveness of the simulators manufactured and used in our study was based on several well-established aspects, such as expert opinion on how well the simulator content reflects the required skills and knowledge, user opinion, and cost-effectiveness.[13]

In health education, the local manufacture of simulators for training in clinical procedures enables and encourages students and professors to actively engage and develop new ways to assess performance in using these resources. Corroborating our findings, research shows that simulation is more enjoyable, engaging, effective, and safe than traditional lecture-based teaching.[14] Some commercially available simulators are costly to acquire and maintain limiting access by educational institutions. These barriers drive the development of affordable models that are easy to manufacture and replace.[15]

Similar to ours, another study with 91 fourth-year medical students from an institution in western Paraná, Brazil, used simulators for male urogenital training. Forty-five students received guidance and training with simulators, and 46 had only information from theoretical classes. Those trained on simulators had higher scores and greater confidence. In addition, they were twice as likely to get higher scores. Those who only followed the theoretical classes had more difficulty, stress, and anxiety when performing the tasks on the mannequins.[16]

The 2015 Lancet Commission on Global Surgery highlighted the shortage of healthcare professionals providing surgical services, especially in low and middle-income countries, leaving 5 billion people without access to surgical care. In some countries, postgraduate training is not required for surgery, increasing the need to train surgically competent generalists. This is challenging due to the lack of faculty, the large number of students, the priority of residents in healthcare settings, and the workload of supervisors. Simulation-based surgical training may help address these challenges.[17,18]

This study has limitations. First, the number of participants is relatively small, which may compromise the representativeness of the results. In addition, the limited variety of synthetic models simulating surgical procedures restricts the comprehensiveness of the conclusions, potentially diminishing the impact of the study.

Despite these limitations, we achieved our main objective, i.e., to develop and evaluate low-cost synthetic models as practical, accessible, and scalable tools for early surgical training focusing on plastic surgery. These models were designed to enable procedures such as resections, mobilizations, and rotations with a degree of realism appropriate for basic training.

Some biological materials traditionally used for this type of training, such as bovine tongues, may offer specific advantages. Synthetic models have additional benefits, such as practicality and safety, eliminating the handling and disposal of organic materials, which require care, reproducibility and standardization, as anatomical characteristics are consistent, ensuring uniformity in training, and sustainability and accessibility, as the materials are easy to acquire, allowing modular component replacement and reducing operating costs.

Recent studies corroborate the effectiveness of synthetic models in surgical education. A recent systematic review with 57 articles highlights that non-biological simulators are effective in acquiring motor skills and increasing learners' confidence in the initial training stages of microsurgical techniques in plastic surgery. In addition, they are widely accepted as viable and economical alternatives.[19] Awad et al (2023) demonstrated that foam-based models for skin suture training are a high-fidelity non-biological alternative and not inferior to other high-cost materials.[20] Another systematic review on microsurgical training reinforces that synthetic simulators are viable for initial teaching, reducing the need for biological and animal models.[21] These findings support our results as 88% of participants reported significant improvement in learning and confidence after training with synthetic models compared with theoretical classes.

It is worth noting that our models do not intend to replace more advanced approaches, but rather complement practical teaching, providing an accessible and efficient alternative for introducing technical skills. Their simplicity and cost-effectiveness allow for greater scalability and democratization of access to surgical training.

It is essential to increase the number of participants and diversify the synthetic models to improve the validity and reliability of the results. These actions would not only strengthen the reliability of the conclusions but also increase the impact of the study, providing a more robust basis for the practical application of the findings. For future studies, we also recommend expanding the evaluation of different synthetic materials to improve the realism of the models, conducting direct comparisons between the effectiveness of biological and synthetic models in advanced training, and expanding both the number of participants and the techniques evaluated. Despite the limitations, the data show that low-cost simulators allow training in surgical skills.

Conclusion

Practical simulation using low-cost models for training in different plastic surgery techniques has proven to be an effective teaching method. In addition, it offers a safe learning environment, reducing insecurity and improving students' preparedness and confidence to interact with actual patients in the future. Thus, students face challenging situations, see the consequences of their actions, and receive immediate feedback. This interactive learning develops clinical judgment, error recognition, and management, reducing risks and increasing patient safety.

It is noteworthy that the early introduction of simulation into the medical curriculum provides significant learning linking theory and practice. Other institutions can replicate the models described and used in this study to disseminate medical-surgical education.

Authors' Contribution

ADVF: final manuscript approval, conceptualization, resource management, writing - original draft preparation; IRRS: data analysis, interpretation, or both, data collection, investigation, methodology, writing - original draft preparation; LLS: statistical analysis, funding acquisition, study conception and design, writing - original draft preparation, visualization; LBC: data analysis, interpretation, or both, final manuscript approval, conceptualization, project management, investigation, writing - review and editing, supervision, validation.

Financial Source

The authors received no funding for this study.

Clinical Trial

None.

Conflict of Interests

The authors have no conflict of interest to declare.

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