Review Article

Surgical simulation education in plastic surgery: current state of the art and need for improvement

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Abstract: Simulation tools continue to play an important part in surgical education, particularly allowing junior trainees an opportunity to familiarize themselves with various procedures that they either have not been exposed to or have not had enough repetition to feel confident enough to execute. It is particularly relevant when surgical training is interrupted due to unforeseen circumstances (i.e., coronavirus disease 2019, also called COVID-19) or to personal reasons (i.e., pregnancy, leave of absence). The ability to remotely work on technical skills has tremendous value and is certainly one of the reasons that we have continued to develop new surgical simulation tools, particularly in the field of plastic surgery. A review of the major surgical simulation and anatomy software tools available within the various subdivisions of plastic surgery such as craniofacial, microsurgery, aesthetic, hand/upper extremity and burn was performed. We also reviewed some of the simulation tools available in other surgical specialties and evaluated them for fit and utility in plastic and reconstructive surgery (PRS) surgical education. Our study shows that while various surgical simulators have been developed in PRS over the years, there remains a gap in terms of the ability for residents and trainees to acquire real-life skills remotely along with the capability to receive live feedback from faculty. This review shows that further tools need to be developed to optimize the acquisition and maintenance of surgical skills in a remote fashion. Taken together, it provides an overview of the evolution of surgical simulation education within plastic surgery.

Keywords: Surgical education; plastic surgery simulation; surgical simulation

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Introduction

Simulation tools, particularly in technically demanding specialties like surgery have the potential to enhance resident education and to elevate proficiency levels (1). As such, they continue to play an important part in surgical education, particularly allowing junior trainees an opportunity to familiarize themselves with various procedures that they either have not been exposed to or have not had enough repetition to feel confident enough to execute.

With a myriad of simulators available, surgical residents in training can familiarize themselves with anatomy and the basic steps of many procedures such as cleft palate repair, rhinoplasties, and other craniofacial surgeries. Additionally, by practicing in a particularly low-stress setting, these surgical simulators are valuable assets to medical training, as residents can practice skills prior to operating on live patients where stakes are increased and the additional pressures of being in the operating room (OR) are ever present.

Although simulators often lack the tactile feel of a true operating setting, they become critical in times where education is interrupted for an extended period due to personal reasons (i.e., pregnancy, leave of absence) or wide-scale disruption stemming from challenging circumstances (i.e., war, natural disaster). The past couple of years in particular, due to the coronavirus disease 2019 (COVID-19) pandemic, elective surgeries were canceled nationwide in the United States for several months, which have negatively impacted surgical education.

For plastic surgeries trainees specifically, the technical skills required in microsurgery, cleft lip and palate and operating in confined spaces can be affected by the decrease in surgical volume. Given that plastic surgeons operate in all areas of the body, knowledge of anatomy and extensive practice in various layers and planes are key to successful surgeries ranging from burns to intravascularly. Thus, implementing these tools during formative years of residency education can be instrumental in developing the hand-eye fine motor coordination needed to operate.

To date, relatively few non-virtual simulators have been designed and implemented for the expressed purpose of plastic surgical education (2). While several options exist for three-dimensional (3D) surgical planning (3), there remains a significant need for tools to be developed to optimize the acquisition and maintenance of surgical skills in a remote fashion. We provide here a comprehensive review and discussion of the evolution of surgical simulation education tools within plastic surgery (*Table 1*).

Methods

Surgical tools were reviewed using PubMed searches in aspects involving craniofacial, microsurgery, hand and upper extremity, aesthetic, burn, and full body models. Repeat results were not included. The search term "cleft palate repair simulator" in PubMed resulted in 75 articles with seven different simulation tools referenced when examining craniofacial surgical simulators. For microsurgery, "microsurgery simulation tool" was searched on PubMed with a yield of 89 results. From these results, top commercial tools and standardized kits and materials were reviewed with 16 articles ultimately referenced. Regarding hand and upper extremity surgical simulation tools, only one other tool was referenced in addition to a simulator developed in-house by one of the co-authors (A Prsic). In terms of "mammoplasty surgical simulators", PubMed searches for "mammoplasty simulator" resulted in 122 articles. "Burn simulation tool" as a search term resulted in 118 articles. From these, four of the most widely-known simulators were investigated. In considering full-body simulators such as cadavers and other animal models, only 50 results in PubMed were returned with "full body simulation tools" entered as a search term. From these, two articles were reviewed and discussed.

Craniofacial

Among the first in this category to be developed was the cleft palate repair simulator (4) developed by Vadodaria *et al.* in 2007. It provides trainees with an opportunity to learn a few basic skills of cleft palate repair, including cutting and suturing under magnification in a limited area such as the oral cavity of a 6-month-old baby. One limitation of this simulation tool is the inability to simulate the release of soft tissue from the hard palate as further refinements are required for making the simulator more useful for learning the skills of delicate dissection of the mucoperiosteum and nasal lining from the hard palate and velar muscles. Overall, this tool is helpful for microscope discipline, familiarization with working in a small and narrow space as well as suturing at depth.

The cleft lip simulator (5) developed by Podolsky *et al.* is another simulation tool that comprises multilayered soft tissues, bone, and realistic dissection planes that was developed using 3D printing, adhesive and polymer techniques. One advantage of this tool is that it comprises detailed, accurate anatomy and multi-layered tissue planes that allow for a complete end-to-end unilateral cleft lip repair using real surgical instruments making it quite a realistic model. This model now distributed by Simulare Medical, a branch of Smile Train—the world's largest cleft charity—has been shown to be effective in training surgeons for cleft lip and palate repair in low-income countries (6,7). More extensive primary rhinoplasty procedures including nostril rim incisions and other rhinoplasty approaches are technically also possible given the accuracy of the simulator's anatomy. One limitation of this simulator is its cost, as a single unit sells for approximately US $250. A similar available tool is Reighard *et al.'s* cleft lip repair simulator (8), which consists of readily available materials, features compatibility with standard surgical equipment, and a reusable-replaceable modular design resulting in a relatively low overall cost, making it more accessible. A limitation of

Table 1 Summary of PubMed cited options for surgical education simulations used in plastic surgery

Category	Surgical simulation	Cost*	Levels of realism	Pros	Cons
Craniofacial	Cleft palate repair simulator (4)	Under $50	Low fidelity	Cheap, familiarization with working in small, narrow cavity	Too simplistic, no multiplane layers for dissection
	Cleft lip simulator (5-7)	$2,400 for single cleft palate kit, $1,600 for single cleft lip kit	High fidelity	Accurate, great tactile feel, great/complex anatomy	Expensive, limited inventory
	Cleft lip repair simulator (8)	$11.43 for reusable molding system, $4.59 for single-use cleft model	High fidelity	Cost effective, materials readily available, usability	Suboptimal muscle layer dissection
	The Smile Train Simulator for Cleft and Craniofacial Surgery (9)	Open access	High fidelity	Simplifies complex three-dimensional surgical concepts	No hardware involved, no tactile feedback
	MyFace45 Simulator for Cleft and Craniofacial Surgery (10)	Open access	Low fidelity	Great for preoperative planning, particularly for complex forms of craniosynostosis	No hardware involved, no tactile feedback
	Anatomical Simulator for Craniosynostosis Surgical Training (11)	$600	High fidelity	All surgical steps simulated, great tactile feedback, great anatomy including bleeding effect, ability for post op imaging studies	Expensive, time consuming to produce unit
	3D printed cleft palate simulator (12)	$29 for exchangeable cartridge	High fidelity	Cost effective	High learning curve for beginners
	Mandibular distraction osteogenesis (MDO) simulator (13)	Consumable material costs $9.39	Adequate fidelity	Cost effective, ease of use	Fidelity/anatomy can be improved
Microsurgery	Biomet anastomosis kit (14)	Negligible (2- and 3-mm polyvinyl tubes, foam background, dye)	Low fidelity	Cost effective, ease of use, no set up or hardware necessary, can use on-the-go	Too simplistic, suboptimal tactile feedback
	PracticeRat (15)	$1,250	High fidelity	Cost effective, ease of use, no set up or hardware necessary, can use on-the-go	Too simplistic, suboptimal tactile feedback
	The Anastomosis Device (16)	Not listed	High fidelity	Cost effective, ease of use, no set up or hardware necessary, can use on-the-go	Too simplistic, suboptimal tactile feedback
	The MD PVC Rat (16,17)	Not listed	High fidelity	Cost effective, ease of use, no set up or hardware necessary, can use on-the-go	Too simplistic, suboptimal tactile feedback
	Stanford Microsurgery simulation system (18,19)	Not listed	High fidelity	Cost effective, ease of use, no set up or hardware necessary, can use on-the-go	Too simplistic, suboptimal tactile feedback
	MicroSim (20)	Not listed	High fidelity	Realistic user interface with real world scenarios	Virtual, no tactile feedback, multi sensor camera needed, learning curve, frequent software bugs
	Digital Microsurgical Pre-Trainer (21)	Negligible	Low fidelity	Cost effective, ease of use, no set up or hardware necessary, can use on-the-go	Too simplistic, suboptimal tactile feedback
	Boston Dynamics Surgical simulator (22)	Free	Low fidelity	Cost effective, ease of use, no set up or hardware necessary, can use on-the-go	Too simplistic, suboptimal tactile feedback
	Synthetics: rubber gloves (23), surgical gauze (24), beads (25), sewing needles (26), silastic tubes (27) and Japanese noodle (28)	Negligible	Low fidelity	Cost effective, ease of use, no set up or hardware necessary, can use on-the-go	Too simplistic, suboptimal tactile feedback
	Holographic augmented reality (29)	Not listed, developed in-house	High fidelity	Easy workflow, anatomy stays correctly fused with the patient regardless of position changes	Poor image depth, image can only be visualized, unable to interact with image, requires a head-mounted display
Hand/upper extremity	3D-printed hand/hand fracture fixation training instrument (30)	$40	High fidelity	Cost effective, ease of use, no set up needed, can use on-the-go, allows for multiple use	Limited anatomical variety, ideal only for bony and skin replica
	Tactical Hand Simulator (31)	$150	High fidelity	Cost effective, ease of use, no set up needed, can use on-the-go, allows for multiple use	Limited anatomical variety, ideal only for bony and skin replica
Aesthetic	The mammoplasty part-task trainer (MPT) (32)	$83.73	High fidelity	Good overall haptic feedback from implant insertion and pocket creation	Unilateral only, skin only with no muscle simulation below and therefore offers limited dissection
	3D printed multilayer facial flap (33)	Not listed	High fidelity	Good overall haptic feedback for local flap, cost effective	Limited use in one area, simulation of skin only
Burn	Moulage as burn simulation (34,35)	Negligible	High fidelity	Realistic	Time consuming, requires artistic expertise
	The Burns Suite (TBS) (36)	Negligible	High fidelity	Great for contextualized pediatric burns resuscitation simulation scenario	Extensive set up required
	SimMan mannequin (37)	$21,620–27,950, used is $4,600	High fidelity	Great for simulation-based scenarios	Expensive, extensive set up required
Full body	Perfused/pressurized fresh human cadaver (38)	$500–5,000	High fidelity	Optimal practice environment using real human tissue	Expensive, limited number of uses
	Animal models (39-42) for microsurgery training, flap raising, facial surgery, and hand surgery: pig, chicken, rat, dog, monkey, sheep and earthworms	$100–200	High fidelity	Great substitute for human tissue	Expensive, limited number of uses
Anatomy software	NetAnatomy, Vesalius3D, Anatomage, Anatomy Studio, BodyViz, BioDigital, Toltech, Atlas (Human Anatomy Atlas) for mobile phones	Great variability from free to $299	Low fidelity	Allows for repeated, on demand visualization of anatomy, ease of use, low learning curve	Virtual, no tactile feedback, often too simplistic, complex models can be expensive

* denotes US dollars. 3D, three-dimensional.

this model however—which the designers admit to—is the less realistic simulated muscle layer dissection and closure which ideally needs several minor modifications that would help enhance the model for use in a truly emulative training environment, although their aim is to balance necessary features with added cost.

Another craniofacial simulation tool is the Smile Train Simulator for Cleft and Craniofacial Surgery (9). This tool was created by Smile Train in partnership with BioDigital, and is a virtual surgery simulator that is the first web-based, 3D interactive surgical explorer for cleft care. It was originally designed to train surgeons in developing countries to repair cleft lip and palate and allows for quick grasp of complex 3D surgical concepts that are essential in cleft lip and palate procedures. In addition, it allows trainees to become familiar with pertinent surgical anatomy of cleft deformities, surgical markings, and the cardinal procedures in cleft surgery through animation and intraoperative video footage with voiceover narration. Although it is free and open-access-based, one clear limitation is that it is virtual only and does not allow for a tactile feel, which constitutes a significant component of surgery especially at the trainee level. Another virtual craniofacial simulation tool is the MyFace45 Simulator for Cleft and Craniofacial Surgery (10). This tool was created by a partnership of philanthropy, industry, the Institute of Reconstructive Plastic Surgery, and the Department of Plastic Surgery at NYU Langone Medical Center and allows a trainee/user to trigger intraoperative surgical videos, voice over, images and 3D labels at various points in a procedure. The MyFace45 Simulator for Cleft and Craniofacial Surgery has a relatively broad spectrum compared to the other virtual simulators and demonstrates nine craniofacial surgery procedures including: Lefort I, Bilateral Sagittal Split Osteotomy, Vertical Ramus Osteotomy, Osseous Genioplasty, Lefort III, Frontal Orbital Advancement/Cranial Vault Remodeling, Lefort III Advancement, Lefort III Distraction, Monobloc Advancement and, Monobloc Distraction. Just like the Smile Train Simulator, it is free access but lacks the important tactile component and works well as a supplemental tool rather than a primary tool for junior trainee surgical learning.

Another simulation tool developed primarily for pediatric neurosurgery simulation is the craniosynostosis surgical simulator called Anatomical Simulator for Pediatric Neurosurgery (11). It is a fairly realistic simulator built with a synthetic thermo-retractile and thermo-sensible rubber which, when combined with different polymers, produces more than 30 different formulas. These formulas present textures, consistencies, and mechanical resistance similar to many human tissues. One great innovative advantage of this tool is that it is possible to perform computerized tomography images due to the radiopacity of this simulator and to compare the pre- and postoperative images. In addition, this simulator includes all necessary planning steps of the surgery, from positioning to skin closure and it is possible to do the skin incision, dissection by planes, osteotomies, and cranial remodeling, using simultaneously both hands and feeling their interaction with the diverse consistencies and resistances of different tissues. Disadvantages of this model however are that it can be difficult and extremely time consuming to create and also the high estimated cost for each surgical unit. The single sheep cranium for example, when compared to this realistic simulator, is far less expensive. While the cost for a sheep cranium is around US $1 and $200 dollars in Brazil (where the model is made), the estimated cost for the realistic simulator unit is US $600. However, it provides a great alternative to the use of animal models and human cadaveric specimens.

3D-printed cleft palate simulator from high resolution computed tomography (CT) scan of pathological specimen and then molded in plastic and layers of silicone to create "soft tissue" components (12). The neonatal mandibular distraction osteogenesis (MDO) simulator is a novel, low-cost, high-fidelity simulation tool out of the University of Michigan also with computer-aided design (13).

Microsurgery

The Biomet anastomosis kit (14) is a microsurgery simulation tool which offers trainees an opportunity to inexpensively, safely, and reproducibly teach and perfect microsurgical skills. The Biomet training set consists of several items, including 2- and 3-mm polyvinyl tubes (used to simulate blood vessels), a foam background, a double-opposing Ackland clamp, microvascular suture, and a particulate dye used to test vessel patency after microvascular anastomosis. This set provides a valuable alternative to animal-based skills laboratories. PracticeRat (15), the Anastomosis Device (16) and the MD PVC Rat (16) are 3 commercially available microsurgery simulators. They feature latex blood vessels and allow for end-to-side or side-to-side anastomosis as well as adventitial stripping simulation. However, these models have been associated with high costs that can be even greater than animal models (17). Another microsurgery simulation tool is the Stanford Microsurgery simulation system (2,18). It is a virtual application for microsurgical training, in which the user sutures together virtual blood vessels. The simulation system allows the performance of a vessel end-to-end anastomosis virtually. The user/trainee has complete control of the view, and may use stereo glasses for true binocular depth perception. Several other similar virtual microsurgery simulators have been described (19). Examples are the MicroSim (20), Digital Microsurgical Pre-Trainer (21) and the Boston Dynamics Surgical simulator (22).

To date, the use of synthetics remains one of the oldest and most common methods for microsurgical simulation and offers quite a variety of options. They include the use of rubber gloves (23), surgical gauze (24) with the goal of passing a needle on and under the fibers of the surgical gauze and forming micro-knots, beads (25) where the goal is to produce micro-necklaces thread segments, sewing needles (26) which consists of passing wires in the eye of sewing needles arranged into a circle, silastic tubes (27) and Japanese noodle (28). Lastly, a recent paper presented the use of holographic augmented reality as a novel modality to help with deep inferior epigastric perforator (DIEP) flap harvest by superimposing a CT-generated arteriogram to the patient for direct visualization of perforator vessel (29).

Hand/upper extremity

The 3D-printed hand/hand fracture fixation training instrument (30) is a low cost (US $40), realistic 3D hand model with interchangeable bones. It was designed during the COVID-19 pandemic by Yale University to provide its junior PRS residents with a fluoroscopy-free percutaneous Kirschner wire (K wires) hand fracture fixation training instrument kit for home-based skill acquisition. The most significant limitations of this model are the need for a 3D printer and its associated overhead and maintenance costs, as well as the limited number of attempted fixations of the interchangeable bones (i.e., bones can only be used to drill up to 6 to 8 different entry points) requiring relatively frequent replacements (US $2/bone). The Tactical Hand Simulator (31) is a relatively similar 3D model designed to develop competency in percutaneous pinning in residents. It is made of a 3D-printed skeletal structure embedded in a ballistic gel matrix so that each bone piece is independently suspended in the gel. While its overall anatomic accuracy and cortical-cancellous bone interface constitutes the models' strengths, its lowest rated features are the skin and the joints simulation as well as its price (US $100).

Aesthetic

The mammoplasty part-task trainer (MPT) (32) described by Kazan *et al.* is a novel mammoplasty simulator designed to have a reusable and rigid thorax base and "soft" disposable layers to mimic the skin and subcutaneous tissues of the breast. It is used primarily for simulation of aesthetic surgery procedures such as augmentation mammoplasty. The MPT was produced in an "anatomic" layer-by-layer manner. The external appearance and shape of the breast were reproduced from the right breast of a volunteer. A mold of the breast and chest wall taken by applying silicone to the breast in multiple layers with incremental viscosity makes for a realistic experience in terms of tactile feel and tissue consistency. Limitations of this tool are the material used to simulate the subcutaneous tissue not quite mimicking the breast parenchyma texture with lack of resistance, resulting in tearing upon suturing. Another limitation is the lack of bilateral breast models, which does not allow for comparison of symmetry. In terms of facial defects and reconstruction, the 3D-printed multilayer facial flap is a 3D-printed facial flap simulator designed from a CT scan and manufactured out of silicone for low-cost, high-fidelity simulation (33). Although primarily tested by a group of Otolaryngology-Head and Neck Surgery trainees at the University of Michigan, early feedback has shown it to be an effective and useful training tool with a high level of realism in surgical education of facial reconstruction.

Burn

While simulation tools for burn management skill acquisition are not as developed as craniofacial or other fields in plastic surgery, there have been a few low-cost methods used over the years to help enhance trainees' experiences. One of them is the use of moulage as burn simulation (34), where makeup artists use professional techniques to produce wounds, blisters and eschar. Overall, it can be argued that high quality moulage can play an important role in encouraging trainees to suspend disbelief and treat standardized patients as real burns victims, which can only help enhance their learning. However, there is limited evidence of the validity of using moulage as a simulation tool and a recent study suggests that it actually leads to inferior participant assessment scores compared with an electronic mannequin (35). Another burn simulation tool is The Burns Suite (TBS) (36). It involves creating a burns scenario in a novel, low-cost, high-fidelity, portable, immersive simulation environment. Specifically, TBS involves a portable, versatile simulated environment that uses an inflatable 360° enclosure to provide a self-contained "shell" (or "igloo"), which screens participants from their surroundings. The concept relies on generating the illusion of a specific environment to be created in any available space. A limitation of this tool is the lack of a more realistic experience when it comes to performing actual procedures that are done in a real burn situation.

A more realistic burn simulation tool is the SimMan mannequin (37) which is a tool primarily used by emergency medicine trainees. It helps users/trainees learn how to care for burn victims and to treat injuries secondary to smoke inhalation through simulation-based medical training.

Full-body models

The use of cadavers for surgical training simulation continues to be a significant asset among training programs. In recent years, the use of perfused/pressurized fresh human cadavers (38) has made for a much more realistic experience as the perfused cadaver model results in tissues that bleed when cut, pulsatile vasculature for exposure, physiologic pressurized vessels for venous and arterial access and the ability to recreate high-risk injuries for surgical team crisis training. However, the total cost of a single perfused cadaver model (~US $3,000) continues to be a significant barrier to access.

Animal models have also traditionally been used a full-body model for microsurgery training, flap raising, facial surgery, and hand surgery (39). This includes pig, chicken, rat, dog, monkey, sheep, and earthworms as the main models. As new tools and technology emerge, the use of animal models will likely continue to play an important role in surgical simulation as it provides for the most realistic feel for practice.

Anatomy software

Although they are not necessarily considered surgical simulation models in the same fashion as the various models previously described, there have been a number of both web and smartphone-based application and software that are geared towards teaching anatomy without the need of a cadaver or an animal model. The following list is not meant to be exhaustive but rather includes some of the main players that fit the model of virtual interactive anatomy. This includes: NetAnatomy, Vesalius, Anatomage, Anatomy Studio, BodyViz, BioDigital, Toltech, and Atlas (Human Anatomy Atlas). There has also been a recent flow of virtual courses and curriculum making use of technology for the purposes of teaching or improving surgical technique. A recent example is that of a virtual surgical dissection course, making use of 3D-printed surgical simulators in order to teach trainees/fellows advanced surgical techniques in a low-risk, virtual environment (40).

Non-PubMed cited tools

In addition to the aforementioned PubMed cited resources, there exist a number of useful interventions worth discussing as part of the broader available options for surgical education. While this is not meant to be an exhaustive list, we will highlight a few of the more innovative approaches that folks have taken to bridge the low-cost learning, particularly in the remote setting. The "blue blood" chicken thigh microsurgery model established by the University of Wisconsin offers an innovative way to perform high fidelity microsurgery using off the shelf chicken thighs (https://www.youtube.com/watch?v=rEZGwbdpGuw&t=1s). There are a number of arts-based interventions similar to those of 'The Breakfasteur' on YouTube that refreshes trainees' anatomy knowledge in an engaging way through re-creation of the anatomical structures. Other examples have made use of posted kits and Zoom, or other animation-based medium such as https://pie.med.utoronto.ca/TVASurg and https://fundamentalsurgery.com to promote recall of anatomy knowledge. Companies such as Surgical Art in the United Kingdom are using very cheap alternatives to train surgeons such as chicken bones from fast-food restaurants, crochet hoops and even multi-modal face models (http://www.surgical-art.com).

Discussion

Although we have made tremendous progress over the years in terms of designing ways to improve surgical education in plastic surgery with simulation tools, there remains a significant need for innovation in the field. Our review across the different subfields of plastic surgery has emphasized the absence of concrete methods and tools for surgical skills acquisition in the remote setting for residents and trainees.

A number of cleft lip/palate repair and other realistic craniofacial simulation tools have been developed, but for the most part lack the ability to simulate the release of soft tissue from the hard palate and the associated delicate dissection of the nasal lining. The models exhibiting great anatomy prove to be relatively expensive making it a challenge for programs and trainees to use at scale. The microsurgery simulation tools are largely synthetics-based, which allow for a relatively inexpensive and easy to set up option. However, replicating the tactile feel in those methods can be improved. The number of hand/upper extremity as well as burn simulation models has been limited but existing options allow real-time visual feedback and a rudimentary grasp of the basics. More simulation tools are needed for other types of hand fracture fixations as well as non-fracture-based procedures. Aesthetic simulation tools are also very rare and are mostly limited to breast reconstruction models. While they portray the anatomy well, one criticism of such models has been that the subcutaneous tissue does not quite mimic the breast parenchyma texture.

The most novelty we have seen in surgical simulation to date still predominantly lies within the development of phone and web-based applications, virtual anatomy laboratories and software allowing for 3D visualizations. Unfortunately, they all lack a tactile feel that could replicate the OR experience and perhaps most importantly lack the feedback component allowing for residents to communicate with faculty. The need for innovation is further evident in the context of a pandemic, which has halted surgical education across the globe. We have seen elective surgeries being canceled for a significant period of time during which residents did not have concrete options to acquire or enhance their surgical skills remotely while receiving feedback and guidance from faculty.

We think it is critical for the medical education community at large to focus on and develop simulation tools that will help complement resident education (43,44). Whether the COVID-19 pandemic persists or similar events were to happen in the future, we need to be ready and able to respond from an education standpoint. Specifically, we need to design tools that replicate the OR experience as close as possible and also that allow for feedback from faculty to trainee. These surgical simulators also need to be affordable to allow for scalability and adequate practice by trainees.

Conclusions

This review provides an extensive overview of the landscape of surgical simulation education tools available in plastic surgery. Significant progress has been made in the last two decades in terms of the design of innovative tools mimicking the surgical experience for the trainee. Nonetheless, there remains a need for more practical, realistic and affordable tools able to leverage available technologies to enhance the plastic surgery trainee's experience.

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Footnote

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

References

1. El Ahmadieh TY, Aoun SG, El Tecle NE, et al. A didactic and hands-on module enhances resident microsurgical knowledge and technical skill. Neurosurgery 2013;73 Suppl 1:51-6.
2. Kazan R, Cyr S, Hemmerling TM, et al. The Evolution of Surgical Simulation: The Current State and Future Avenues for Plastic Surgery Education. Plast Reconstr Surg 2017;139:533e-43e.
3. Simon Z. Computer-guided implant surgery: placing the perfect implant. J Calif Dent Assoc 2015;43:126-9.
4. Vadodaria S, Watkin N, Thiessen F, et al. The first cleft palate simulator. Plast Reconstr Surg 2007;120:259-61.
5. Podolsky DJ, Wong Riff KW, Drake JM, et al. A High Fidelity Cleft Lip Simulator. Plast Reconstr Surg Glob Open 2018;6:e1871.
6. Borg TM, Solomon S, Alfarrouh R, et al. Simulation

Training Approach for Cleft Lip and Palate Repair in Low-Income Countries. Cleft Palate Craniofac J 2022. [Epub ahead of print]. doi: 10.1177/10556656221136650.
7. Smerica AM, Hamilton SC, Dibbs RP, et al. Smile Train: A Sustainable Approach to Global Cleft Care. J Craniofac Surg 2022;33:409-12.
8. Reighard CL, Green K, Rooney DM, et al. Development of a Novel, Low-Cost, High-fidelity Cleft Lip Repair Surgical Simulator Using Computer-Aided Design and 3-Dimensional Printing. JAMA Facial Plast Surg 2019;21:77-9.
9. BioDigital. Smile Train Virtual Surgery Simulator [Internet]. Available online: https://www.smiletrain.org/medical/training/virtual-surgery-simulator
10. Flores RL, Oliker A, McCarthy JG. An Internet-Based Surgical Simulator for Craniofacial Surgery. Plast Reconstr Surg 2015;136:8.
11. Coelho G, Warf B, Lyra M, et al. Anatomical pediatric model for craniosynostosis surgical training. Childs Nerv Syst 2014;30:2009-14.
12. Nicholas R, Heinze Z, Papavasiliou T, et al. Educational impact of a novel cleft palate surgical simulator: Improvement in surgical trainees' knowledge and confidence. J Plast Reconstr Aesthet Surg 2022;75:3817-25.
13. Reighard CL, Powell AR, Zurawski TY, et al. Development of a novel mandibular distraction osteogenesis simulator using Computer Aided Design and 3D printing. Int J Pediatr Otorhinolaryngol 2021;142:110616.
14. Soto-Miranda MA, Ver Halen JP. Description and implementation of an ex vivo simulator kit for developing microsurgery skills. Ann Plast Surg 2014;72:S208-12.
15. Weber D, Moser N, Rösslein R. A synthetic model for microsurgical training: a surgical contribution to reduce the number of animal experiments. Eur J Pediatr Surg 1997;7:204-6.
16. Remie R. The PVC-rat and other alternatives in microsurgical training. Lab Anim (NY) 2001;30:48-52.
17. Yen DM, Arroyo R, Berezniak R, et al. New model for microsurgical training and skills maintenance. Microsurgery 1995;16:760-2.
18. Brown J, Montgomery K, Latombe JC, et al. A microsurgery simulation system. In: Niessen WJ, Viergever MA. editors. Medical Image Computing and Computer-Assisted Intervention – MICCAI 2001. MICCAI 2001. Lecture Notes in Computer Science, vol 2208. Berlin, Heidelberg: Springer, 2001.
19. Abi-Rafeh J, Zammit D, Mojtahed Jaberi M, et al. Nonbiological Microsurgery Simulators in Plastic Surgery Training: A Systematic Review. Plast Reconstr Surg 2019;144:496e-507e.
20. Hüsken N, Schuppe O, Sismanidis E, et al. MicroSim - a microsurgical training simulator. Stud Health Technol Inform 2013;184:205-9.
21. Kazemi H, Rappel JK, Poston T, et al. Assessing suturing techniques using a virtual reality surgical simulator. Microsurgery 2010;30:479-86.
22. O'Toole RV, Playter RR, Krummel TM, et al. Measuring and developing suturing technique with a virtual reality surgical simulator. J Am Coll Surg 1999;189:114-27.
23. Crosby NL, Clapson JB, Buncke HJ, et al. Advanced non-animal microsurgical exercises. Microsurgery 1995;16:655-8.
24. Demirseren ME, Tosa Y, Hosaka Y. Microsurgical training with surgical gauze: the first step. J Reconstr Microsurg 2003;19:385-6.
25. Yenidunya MO, Tsukagoshi T, Hosaka Y. Microsurgical training with beads. J Reconstr Microsurg 1998;14:197-8.
26. Dumont LA, Martinot-duquennoy V, Hubert T, et al. The "double clock" or how to learn microsurgery without animal. Ann Chir Plast Esthet 2011;56:555-7.
27. Brosious JP, Tsuda ST, Menezes JM, et al. Objective evaluation of skill acquisition in novice microsurgeons. J Reconstr Microsurg 2012;28:539-42.
28. Prunières GJ, Taleb C, Hendriks S, et al. Use of the Konnyaku Shirataki noodle as a low fidelity simulation training model for microvascular surgery in the operating theatre. Chir Main 2014;33:106-11.
29. Pietruski P. Holographic Augmented Reality for DIEP Flap Harvest. Plast Reconstr Surg 2021;148:1052e-3e.
30. Prsic A, Boyajian MK, Snapp WK, et al. A 3-Dimensional-Printed Hand Model for Home-Based Acquisition of Fracture Fixation Skills Without Fluoroscopy. J Surg Educ 2020;77:1341-4.
31. Wu YY, Rajaraman M, Guth J, et al. A High-fidelity Tactile Hand Simulator as a Training Tool to Develop Competency in Percutaneous Pinning in Residents. J Am Acad Orthop Surg Glob Res Rev 2018;2:e028.
32. Kazan R, Courteau B, Cyr S, et al. A Novel Mammoplasty Part-Task Trainer for Simulation of Breast Augmentation: Description and Evaluation. Simul Healthc 2016;11:60-4.
33. Yang SF, Powell A, Srinivasan S, et al. Addressing the Pandemic Training Deficiency: Filling the Void with Simulation in Facial Reconstruction. Laryngoscope 2021;131:E2444-8.
34. Pywell MJ, Evgeniou E, Highway K, et al. High fidelity, low cost moulage as a valid simulation tool to improve

burns education. Burns 2016;42:844-52.
35. Lee SK, Pardo M, Gaba D, et al. Trauma assessment training with a patient simulator: a prospective, randomized study. J Trauma 2003;55:651-7.
36. Sadideen H, Wilson D, Moiemen N, et al. Proposing "the burns suite" as a novel simulation tool for advancing the delivery of burns education. J Burn Care Res 2014;35:62-71.
37. Parsons M, Murphy J, Alani S, et al. Thermal Burns and Smoke Inhalation: A Simulation Session. Cureus 2015;7:e360.
38. Carey JN, Minneti M, Leland HA, et al. Perfused fresh cadavers: method for application to surgical simulation. Am J Surg 2015;210:179-87.
39. Loh CYY, Wang AYL, Tiong VTY, et al. Animal models in plastic and reconstructive surgery simulation-a review. J Surg Res 2018;221:232-45.
40. Michaels RE, Zugris NV, Cin MD, et al. A national pediatric otolaryngology fellowship virtual dissection course using 3D printed simulators. Int J Pediatr Otorhinolaryngol 2022;162:111273.
41. Almarghoub MA. A Simple and Cost-effective Method for Practicing Microsurgery. Plast Reconstr Surg Glob Open 2019;7:e2146.
42. Malik MM, Hachach-Haram N, Tahir M, et al. Acquisition of basic microsurgery skills using home-based simulation training: A randomised control study. J Plast Reconstr Aesthet Surg 2017;70:478-86.
43. Saleem HY, Huayllani MT, Boczar D, et al. Creating Competent Plastic Surgeons: The Role of Surgical Simulation. Ann Plast Surg 2020;84:125-6.
44. Al-Bustani S, Halvorson EG. Status of Microsurgical Simulation Training in Plastic Surgery: A Survey of United States Program Directors. Ann Plast Surg 2016;76:713-6.

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