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Education

Synthetic Simulators for Microsurgery Training: A Systematic Review

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Background: Microsurgery has a steep learning curve. Synthetic simulators have proven to be useful training tools for the initial learning stages, as well as being ethically sound, viable, safe, and cost-effective. The objective of this review was to determine the quality, effectiveness, and validity of these simulators as well as to assess their ability to evaluate microsurgical skills.

Methods: A systematic review following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines was performed. We searched databases (Web of Science, Scopus, and PubMed) to identify original articles describing synthetic training models for microsurgery. Three reviewers evaluated articles for inclusion following predefined selection criteria. Data were extracted from full-texts of included articles.

Results: Thirty-nine studies met the inclusion criteria. A total of 38 different devices have been recorded. Microsurgical training devices offer a low-cost, fast, and consistent method to concretely quantify and assess the initial microsurgical skills of trainees using standardized exercises that can be scored by the examiner. According to the authors, the outcomes were satisfactory, with a tangible improvement in microsurgical abilities, despite the lack of a common comparison scale.

Conclusions: Thanks to their availability, cost, and effectiveness, synthetic models are the recommended option to train basic, intermediate and advanced procedures before executing them on in vivo models. *(Plast Reconstr Surg Glob Open 2024; 12:e6004; doi: 10.1097/GOX.0000000000006004; Published online 26 July 2024.)*

INTRODUCTION

Microsurgery is a key element of reconstructive surgery, necessitating intensive training and a steep learning curve before it can be effectively performed.[1,2] Microsurgical skills can be applied in different surgical fields. Indeed, the possibility of performing free tissue transfer, perforator dissection, nerve repair, and lymphatic surgery has revolutionized the surgical management of limb salvage, postoncologic resections, and lymphedema treatment, providing tremendous improvements in patients' quality of life.[3]

Microsurgical training aims to guarantee solid technical bases for overcoming the well-recognized steep learning curve of this surgical technique.[4] Little consensus has been reached to standardize the specific training criteria.[5,6] Surgical simulation has played an essential role in this sense, as numerous living and nonliving models have been described, some of which have been used as objective assessment training tools. The models described in the literature can be divided into three main groups: synthetic, ex vivo, and live animal models. However, even if practicing on living animal models is considered the gold standard before clinical practice, three R principles (replacement, reduction, and refinement)[7] are pushing toward the use of ethically sound, feasible, safe, and cost-effective initial training alternatives. Studies have shown that simulated practice on low-fidelity models was effective in establishing microsurgical skills that can later be transferred to animal or cadaveric models.[8,9]

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Synthetic training tools have been manufactured to acquire the basic microsurgical techniques as well as maintain one's hand dexterity during intervals of ineptitude.[10]

This review critically analyzes literature regarding synthetic microsurgical simulators. It evaluates devices considered as an effective replacement of ex vivo or in vivo models, in terms of dexterity, progression, and microsurgical skills. Moreover, this review aims to establish whether such devices could be used as assessment tools for microsurgical dexterity and progression of microsurgical learning.

MATERIALS AND METHODS

A systematic review was conducted using the transparent Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[11,12] The search strategy was performed throughout the Web of Science, Scopus, and PubMed databases to identify articles describing synthetic devices or training models for microsurgery. These databases were systematically searched for English language papers (published from January 1980 to December 2021) by entering the following keywords and Boolean operators: microsurg* AND (training* OR model OR simulator). Three independent reviewers assessed the articles following inclusion and exclusion criteria in adherence to PRISMA guidelines.

Selection Criteria

All the original articles describing or validating synthetic microsurgery training simulators were included in this systematic review. Scientific articles on in vivo simulation models, reviews, and meeting abstracts were not included. Titles and abstracts were first screened for inclusion or exclusion and, when one could not be discarded, the full text of the article was carefully read. The flow diagram (Fig. 1) details the selection of studies that were collected or excluded. Models and simulators were classified according to the degree of complexity of the techniques practiced, as stated in the previous literature[13]:

- Basic training: microscope handling and operation, instrument handling, knot-tying, and suturing principles;
- Intermediate training: end-to-end anastomosis (in addition to basic skills);
- Advanced training: adventitial stripping, end-to-side anastomosis, side-to-side anastomosis, unequal caliber anastomosis, free graft placement (in addition to basic and intermediate skills).

Data Collection and Analysis

The selected data extracted from each study were collected and included first author, year of publication, type of device, materials, technical information, subjects participating, type of exercises to be trained, number of repetitions, duration, evaluation method, and final outcomes. No statistical analyses were performed because of the wide variety of studies included; some were validation studies, but some were descriptive studies.

> **Takeaways**
>
> **Question:** What is the educational potential of synthetic simulators in microsurgery?
>
> **Findings:** A systematic review was conducted, and 38 articles were retrieved on the topic. We found that microsurgical training devices offer a consistent method to concretely quantify and assess initial microsurgical skills of trainees as well as contribute to their improvement.
>
> **Meaning:** Synthetic models are recommended to train in microsurgical procedures before executing them on in vivo models.

RESULTS

From the original 612 articles found, 39 met the inclusion criteria.[4,8,9,14–49] According to previous literature,[13] each model was classified depending on the degree of difficulty of the exercises trained with the devices: basic (Supplemental Digital Content 1), intermediate (Supplemental Digital Content 2), or advanced (Supplemental Digital Content 3).

(**See table, Supplemental Digital Content 1,** which displays microsurgery simulators for basic skills training. **http://links.lww.com/PRSGO/D370**.) (**See table, Supplemental Digital Content 2,** which displays microsurgery simulator for intermediate skills training. **http://links.lww.com/PRSGO/D371**.) (**See table, Supplemental Digital Content 3,** which displays microsurgery simulators for advanced skills training. **http://links.lww.com/PRSGO/D372**.)

A fourth table, including information on the ability of synthetic microsurgery simulators to assess microsurgical skills and the type of evaluation was created. (**See table, Supplemental Digital Content 4**, which displays information on the ability of synthetic microsurgery simulators to assess microsurgical skills. **http://links.lww.com/PRSGO/D373**.) Among the 39 selected articles, a total of 40 studies focusing on synthetic microsurgery training devices were found, as one article presented two studies on different devices.[29] In 11 studies, the devices were intended for basic skills training[14–24]; in 20, for the practice of intermediate level skills[4,25–43]; and in nine, for advanced skills.[8,9,29,44–49] As two devices were the objects of two articles each,[27,28,31,32] a total of 38 different devices have been recorded. All studies were retrospective.

Devices were fabricated using a variety of materials: 28 synthetic polymers (latex, parafilm, polyurethane, Lucite, polyvinyl chloride, silicone, polytetrafluoroethylene, polyethylene, hydrogel-based gel, polyvinyl alcohol gelatin, surgical gauze, beads, cannulae, and fluid bags); five plant-based (foliage leaf, chive leaf, petal flower, konjac, and paper); three metal (sewing needles); and one virtual reality.

Most of the screened publications (30 of 39, 64%) were mainly descriptive. Only 16 papers analyzed the outcomes obtained using the devices, as most articles only described its technical aspects, intended use, and potential benefits. Studies investigated a target population: the subjects were students, residents, or trainees in 26 cases;

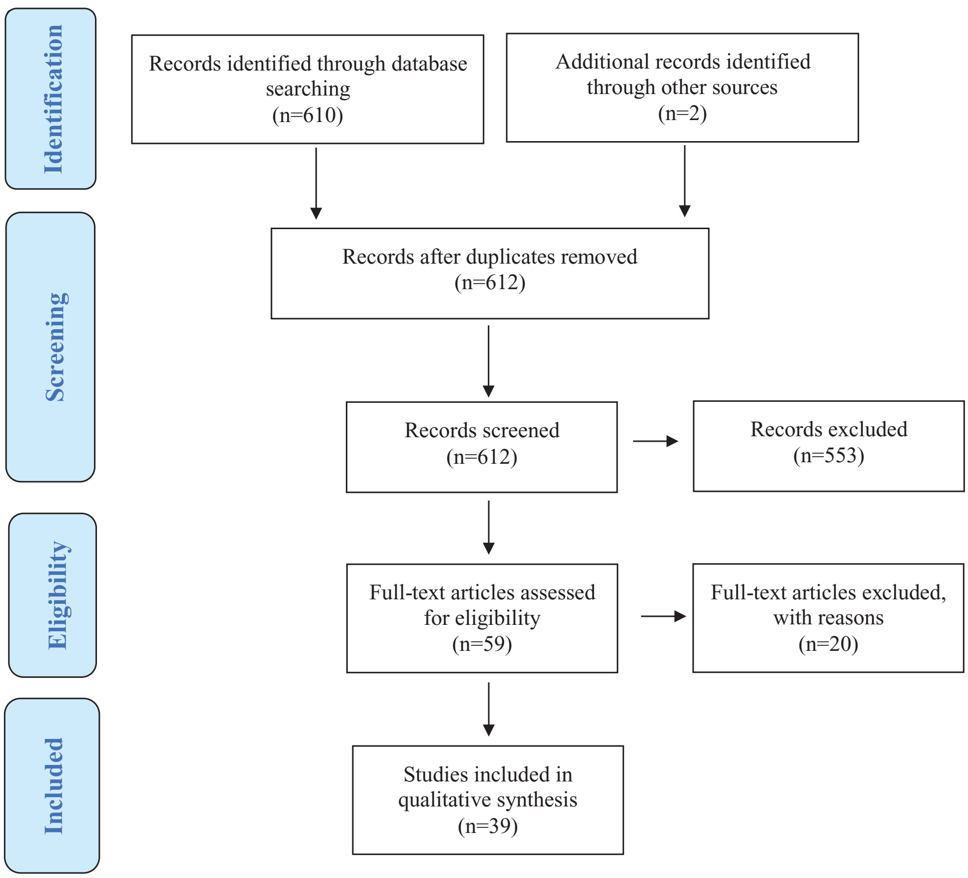

Fig. 1. Flow diagram showing the systematic search strategy conducted in adherence to the PRISMA guidelines.

surgeons in 10 cases; and in three cases, the study population was mixed. According to the authors, the outcomes were satisfactory, with a tangible improvement in microsurgical abilities. Noteworthy, a common scale allowing a comparison among devices was not present in all studies: seven studies used different types of objective measures of ability, ranging from global rating scales[22,32,39] to Objective Structured Assessment of Technical Skills,[38,39] and finally, to task-specific skills checklists like Stanford Microsurgical and Resident Training (SmaRT)[24] and Anastomosis Lapse Index (ALI)[39]. In two cases, devices were used as a preoperative warm-up tool,[31,32] and in one case, they were used to establish the level of microsurgical skills.[32] Training progression was evaluated in 10 studies.[19,21–24,32,36,38,39,41]

DISCUSSION

The acquisition of microsurgical skills requires dedication and continuous training. Despite being the closest model to human live surgery, the use of animal models is expensive[10,50] and involves ethical concerns,[10,51] opening a relevant role to synthetic microsurgical devices. Moreover, prosthetic models are portable, made of long shelf-life materials,[51] and can be used everywhere, even without predisposing a specific environment, thereby potentially increasing their facility of use.

Synthetic microsurgical devices are a useful tool in the young microsurgeon armamentarium. Even though it cannot entirely replace the surgical experience on living models, it is a strong pillar for acquiring basic microsurgical skills.[38] Essential procedures such as microscope and instrumental handling or simple suturing techniques are commonly exercised. Owing to technological advancements, synthetic devices now permit acquisition of intermediate and advanced microsurgical skills, including end-to-end and end-to-side anastomosis as well as free graft placement.[13] In specific cases, synthetic models have proved to be even better than nonvital ones: the use of flower petal, compared with the chicken leg femoral artery, is considered a preferable model when considering the “knot-tying” skill development.[24]

Indeed, they can be used as a propaedeutic step before facing more realistic in vivo models.[10] It should be acknowledged, however, as underlined by Prunières et al,[36] that one of the main drawbacks of the use of synthetic devices is the absence of adventitial spasm and platelet plug formation, despite the intima and media layer being particularly realistic.[39]

The future of microsurgical training will consist of exercising single basic tasks before learning to assemble them together in continuity to reconstruct real-life situations. This strategy will facilitate the transition to human surgery and replication of successful results in patients.[2,52]

Animal cadaveric tissue models are obviously less close to real experience; however, with some adjustments, they can be used to exercise microsurgical procedures in a satisfactory way. In fact, tissue consistency is generally closer to reality compared with synthetic models. Although ex vivo models lack blood flow and thrombosis,[53] an artificial circulation, using dye or blood, can be created to check procedure outcomes.[51,52] The most common being chicken, rat, porcine, and bovine,[10,53] ex vivo models are used to exercise vessel anastomosis, perforator dissection, and nerve repair. With the advantage of being cheaper and more accessible (as animal cadavers can be obtained from laboratory experiments[10]), such models present fewer constraints than living models.[1] Nevertheless, ex vivo models have relevant drawbacks: they have a limited shelf life,[34,52] cannot be introduced in the operating room,[36] and require particular care in instrument cleaning after each training.[34]

The use of human cadavers in microsurgical skills training offers a greater advantage than animal tissue due to its correct anatomy and texture of the tissue. Human models consent to exercise specialized and complex procedures involving flap dissection and harvesting, especially when the cadaver is fresh and perfused.[10,53] Nevertheless, not all institutions benefit from an anatomy facility for surgical training, and the use of ex vivo human derivatives such as the placenta and umbilical cord for training microsurgical procedures has raised ethical issues.[54,55]

Live animal models are considered the gold standard in microsurgical training. Indeed, the young surgeons have to face the real physiologic reactions (such as blood flow, perfusion, and thrombosis) while practicing, thus being very close to human conditions and surgical practice.[10,53] Living rats and pigs are used to exercise intermediate and advanced skills such as anastomosis, flap raising, replantation, transplantation, and more recently, lymphaticovenous bypass.[10,56] However, several disadvantages need to be acknowledged when dealing with this kind of training besides the evident ethical issues,[47,53] such as logistics of animal housing, experimental animal licensing, facility requirements, and of course, drastically increased costs.[50,53]

The evolution of surgical training towards simulation has resulted in the development of microsurgical training devices. As synthetic training devices guarantee many advantages in terms of availability, logistics simplification, cost, and animal use, a number of different models have been developed in the last years.[9,19,21,24,29,38] The rapid diffusion of synthetic devices shows a concrete benefit to improving basic, intermediate, and advanced skills, although being further to reality compared with in vivo or ex vivo models. In clinical activities, training models can also be adopted as a warm-up before the microsurgical act in the operating room, which has been proven to ameliorate surgical skills in follow-up tasks,[57] and as an assessment as well.[22,23]

Another important feature of synthetic devices, underpinned in our review, is their potential role and ability in evaluating the microsurgical skill level of trainees. More specifically, microsurgical training devices offer a low-cost, fast, and consistent method to concretely quantify and assess the initial microsurgical skills of trainees using standardized exercises that can be scored by the examiner.[58] The same procedure may allow reassessment of candidates after training or microsurgical courses to accurately estimate progression and skill acquisition. According to our literature review, microsurgical devices should be considered as a handy warm-up before training on living tissue, as suggested by Woan-Yi Chan et al.[32] Indeed, it improves the steadiness, instrumental handling and speed of executed experienced by the users. Usón and Calles[19] demonstrated that practicing on polyurethane boards before live rats did not affect the novices' ability to perform a patent anastomosis. Significantly fewer live animals were later on needed for training, and this caused a 50% reduction in costs. According to Remie et al,[29] the use of synthetic devices for preliminary training can reduce animal use by approximately 90%. However, this rate may vary greatly according to different studies (range, 10%–90%).[21,29] Unfortunately, no precise cost analysis was reported in any of the reviewed articles.

Nevertheless, this work highlighted how literature lacks a consistent application of such devices in terms of target population. Almost two-thirds of screened publications did not report practical application of the devices to implement microsurgical skills in a defined cohort. Most of the studies were mainly descriptive. In our opinion, a randomized controlled trial, in which several devices may be tested for multiple tasks, would be an interesting option for comparing training models. Another option would be testing different devices by the same students.

Despite the use of different scoring systems[19,21–24,32,38,39] to compare pre- and postutilization, the lack of a commonly validated grading system[10] made it impossible to compare the different devices in terms of both appreciation by the subjects (face validity) and progression in microsurgical skills. Volovici[24] and Cooper[39] used task-specific scores such as SmART and ALI, thus focusing on microvascular training while assessing their device. to become more objective, future studies should compare different cohort of trainees at various point of time in training, using a shared validated score to measure the surgeon's efficacy and quality of work. Global (Objective Structured Assessment of Technical Skills) and task-specific scores (SmART and ALI) should be combined. Additionally, synthetic simulators could be introduced for assessing the trainee's progression throughout the residency program.

Regarding technical aspects of devices, the vast majority used basic equipment and tools. Husken[35] and Remie[29] were the only ones introducing respectively virtual reality and computer programs, thus building more complex and realistic situations for trainees. Overall, devices were quite heterogeneous, which made their comparison difficult. Regarding the exercises, it would be interesting for further articles to distinctly study different types of anastomoses, on nerves, vessels and lymphatics.

Scarcely reported outcomes and poorly detailed methods (eg, many papers missing number of training days/hours required to achieve a certain level) made critical analysis of microsurgical progression quite challenging.

CONCLUSIONS

With the increasing challenges in surgical education, training devices continue to gain importance, resulting in vast simulator development. In this systematic review, we have explored the synthetic simulators that have been developed for microsurgery education, as well as analyzed their ability to evaluate microsurgical skills. Even if high fidelity models such as living animals remain the gold standard, there has been a great evolution in synthetic training devices in recent years. Practicing on ex vivo devices and then upgrading to in vivo models once enough knowledge and skills are acquired represents an ethically acceptable training strategy.

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DISCLOSURE

The authors have no financial interest to declare in relation to the content of this article.

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