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Face and construct validity of a novel simulator for microsurgical education: Microsurgery Arena

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Summary Simulation in microsurgery is essential for skill acquisition and maintenance. This study evaluated the construct and face validity of the Microsurgery Arena, a low-fidelity simulator designed to improve hand and wrist movements under the microscope, enhance instrument handling and knot-tying skills, and consistently assess user performance.

Twenty-one surgical trainees participated in 3-day introductory microsurgical skills courses. Participants performed 2 predefined coordination exercises, “slalom” and “tie-the-knot,” before and after the course. The time required to complete the exercises was recorded. The videos of the exercises were anonymized, randomized, and evaluated by 3 independent raters—a senior experimental microsurgeon, a senior clinical microsurgeon, and a junior resident—using the Stanford Microsurgery Residents Training Scale. Participants also completed demographic and face validity questionnaires at the end of the course.

Quantitative analysis of pre-course scores vs post-course scores showed a statistically significant improvement in all examined skills. Moreover, the face validity assessment revealed highly positive feedback from the participants. The vast majority of candidates found the device extremely or very useful as an initial training model in microsurgery. Moreover, the model demonstrated its ability to discriminate between skill levels before and after training,

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supporting its construct validity. As a low-cost and accessible model, it provides a standardized approach for developing essential microsurgical skills. This simulator has the potential to serve as an effective assessment and training tool for students, residents, and microsurgical novices, contributing to improved skill acquisition in microsurgical training programs.

Competencies
Medical education, Medical knowledge, Practice-based learning and improvement, Systems-based practice.

Microsurgery requires delicate dissections and high-precision sutures. It is therefore essential in several surgical specialties such as plastic and reconstructive surgery, maxillofacial surgery, otorhinolaryngology, neurosurgery, and hand surgery, among others. The possibility to perform free tissue transfer, perforator dissection, nerve repair, and lymphatic surgery has revolutionized the surgical management of post-oncologic resections, severe trauma injuries, limb salvage, and lymphedema treatment, providing considerable improvements in patients' quality of life. As mentioned, microsurgical "know-how" is currently applied in different surgical fields, and the role of microsurgical training in accelerating the learning curve is of paramount importance.[1]

This technique necessitates intensive training to overcome a steep learning curve before effectively performing, despite technical evolution and advancements.[2]

Despite the common agreement regarding the central role that such training has in the development of the required skills, there is a lack of realistic, inexpensive, and easily available training models. Currently, simulation has become an integral part of microsurgical training.[1-3] Models in the literature can be divided into 3 main groups: synthetic models,[4,5] *ex vivo* models,[6-9] and live animal models,[10-12] with ascending levels of accuracy and fidelity. However, although practicing on living animal models is considered the gold standard before clinical practice, animal welfare legislation based on the Three Rs (Replacement, Reduction, and Refinement) strongly encourages the use of ethically sound, safe, feasible, and cost-effective initial training alternatives.[13]

Studies have shown that simulated training on low-fidelity models effectively establishes microsurgical skills that can later be transferred to animal or cadaveric models.[2,3] Recently, low-fidelity non-biological simulators have gained recognition for initial introduction to microsurgery, and a variety of *ex vivo* simulators (either organic or synthetic) have been developed.[14] However, these models are primarily focused on anastomosis-related techniques and are limited in their ability to quantify progress during training. They fail to capture the broader range of skills necessary for comprehensive microsurgical training, such as suturing at various angles, which are essential for advancing surgical expertise.

In search of a device that could not only serve as a dexterity trainer but could also standardize evaluations and allow quantitative measurement of microsurgical skills, we developed the Microsurgery Arena as an innovative, low-cost, portable, and reusable tool.[15] This device serves as both a dexterity trainer and an evaluation tool, offering a clear, standardized method for assessing progress when paired with a validated scoring system. The purpose of this study was to collect subjective evaluations, specifically face validity assessments, from surgeons who utilized the simulator and, most importantly, to examine its validity in objectively assessing essential microsurgical suturing skills, including those related to suturing at various angles, which are critical for advancing surgical expertise.

Material and methods

Microsurgical simulator design and training exercises

To perform this study, we developed a new dedicated microsurgery training device based on the original "round-the-clock" concept.[16] This device is a 5 cm diameter tridimensional training platform for microsurgery, entirely designed to develop wrist movements under the microscope, improve instrument handling, and train the surgical knot under tension. In particular, 2 exercises were specifically designed to practice with this training simulator in accordance with our previous publications and teaching experience.[5,7,15,16]

First, the "slalom" exercise based on the "round-the-clock" concept, consists of passing an 8-0 micro suture "out-in" and "in-out" through each hole of the inner middle circular section of the device. The suture starts going through the 12 o'clock position and continues in a clockwise or counterclockwise direction, depending on the participant's dominant hand. This exercise aims to develop instrument handling and needle coordination in space with different directions and depth perception, as it simulates a 3D environment that requires the practitioner to manipulate the suture in multiple directions and orientations.

Second is the "tie-the-knot" exercise in which the candidate must tie a locking knot pulling together 2 adjacent elastic fibers of a mesh on the device surface (Figure 1). This exercise takes advantage of the elastic proprieties of a 3D-printed silicone mesh. In fact, the knot tends to open if it is not adequately tightened.

The device consists of 2 parts entirely developed by computer-aided design and produced using 3D printing

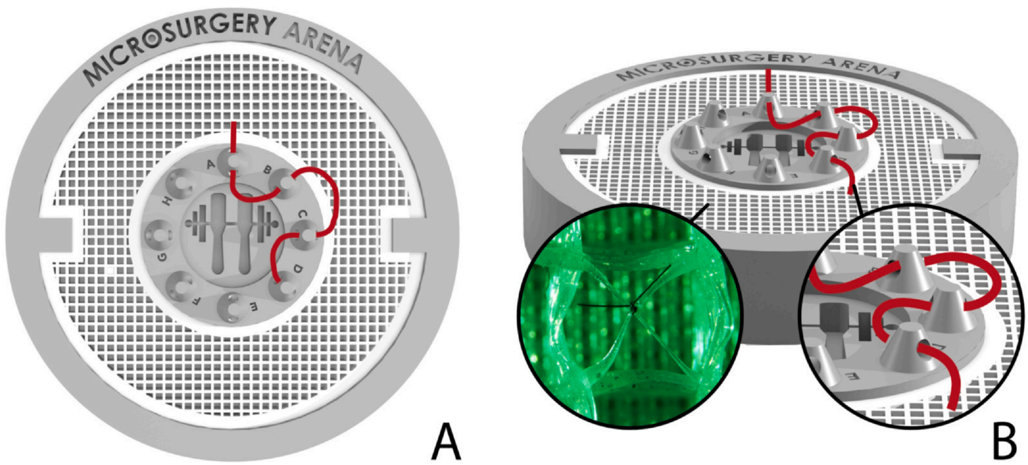

Figure 1 Microsurgery Arena. A) Top view of the microsurgery training device. The circular arena features a central section with 8 cone-shaped projections, each with a through-hole. A red line indicates the path for the "slalom" exercise in which an 8–0 micro suture is passed through the holes in various directions. B) Perspective view of the device with 2 inset magnifications: Left inset (green): Close-up of the 3D-printed silicone mesh surrounding the central area, used for the "tie-the-knot" exercise. Right inset: Detailed view of the cone-shaped projections and the red line demonstrating the suture path for training exercises.

technologies. It comprises a circular base housing the "arena" and a middle circular section with 8 cone-shaped projections with a centripetal through-hole. An interchangeable multilayer elastic mesh surrounds the central area. The device is anchorable to any dry and flat surface using a reusable adhesive disk placed on the bottom of the arena. The in-depth design and development of the device are discussed in a previous paper by the authors[7]. The Microsurgery Arena is commercially available in the United Kingdom and the European Union.

Microsurgical training course and participants

Twenty-one residents and surgical trainees attending basic microsurgery courses at the eSalúdate Simulation Technology Center (Madrid, Spain) were enrolled in the study from January to December 2022. All the participants came from different surgical specialties but were predominantly novices in microsurgery, regardless of their varying degrees of seniority and years of general surgical practice. The demographic data, including their specialties and experience levels, are described in detail in the results section and summarized in the Figure 2.

For this study, the Microsurgery Arena was used for part of the 10-hour microsurgery training course. This intensive program involved a brief theoretical introduction followed by hands-on sessions. Participants began by learning about the microscope and microsurgical instruments before practicing basic suturing techniques on latex gloves and using the Microsurgery Arena. Then, practice on vascular and nerve microdissection and suturing exercises were performed on a chicken wing model. The final two-thirds of the course focused on the practice of microvascular anastomosis, both end-to-end and end-to-side, using chicken wing and thigh models. The Microsurgery Arena was reintroduced at the end of the training to assess the progress of skills learned.

Face and construct validity

Before attending the microsurgery course, each candidate watched a 2-minute introductive video explaining the slalom and tie-the-knot exercises. Then, each candidate performed under video recording an exercise bundle consisting of 3 consecutive and complete slalom exercises followed by a single tie-the-knot.

The face validity of the simulator was assessed through questionnaires completed by the surgeons who used the simulator to evaluate the extent to which the simulator appeared to be effective for its intended purpose.

Subsequently, the candidates attended the microsurgical basic skill course where they could work on vessels between 0.6 mm to 1.5 mm using 2 validated models for microsurgery training: chicken thigh[6-8] and wing.[9] At the end of the course, each candidate performed, under video recording, a new bundle consisting of 3 consecutive and complete slalom exercises followed by a single tie-the-knot. The construct validity of the simulator was evaluated by quantitatively assessing the time taken to complete these tasks, as well as the quality of execution, evaluating the videos using a previously published rating scale.[17] This objective evaluation helped determine how well the simulator measures the specific skills it was designed to assess.

Video recording

To assess the quality of the exercises, each candidate was video recorded using a mobile phone with a high-quality camera (iPhone 12 Pro, Apple Inc., Cupertino, CA, USA) placed on a tripod 15 cm above the table. The camera was located at a 20 cm distance from the Microsurgery Arena and rotated at a 45° angle toward the arena. A full high definition, 30 frames per second video was obtained. The camera position did not interfere with the execution of the exercises, and the tips of the instruments and the arena were visible throughout the exercises (Figure 3).

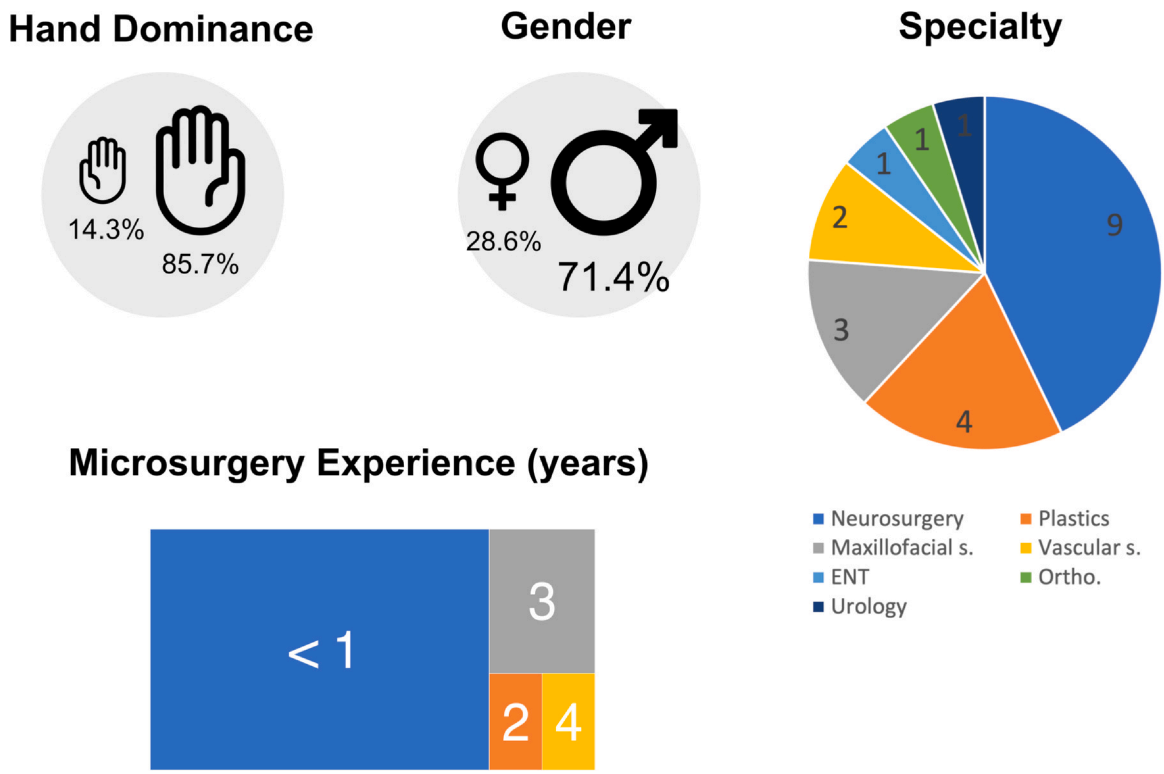

Figure 2 Demographic characteristics of the study participants, including hand dominance, gender distribution, seniority level, years of surgical practice, microsurgical experience, and medical specialties.

Questionnaires

Each individual filled out demographic and face validity questionnaires after the course. The demographic questionnaire evaluated the surgical experience and habits that may affect dexterity in microsurgical procedures, such as hand dominance, gender, surgical domain, seniority level, years of surgical practice, years of microsurgery experience, and use of video games. The face validity questionnaire consisted of 10 questions about the extent of simulator realism and efficacy, and responses followed a 5-point Likert scale format (1= Strongly disagree; 2 = Disagree; 3 = Neither agree nor disagree; 4 = Agree; and 5 = Strongly agree). Participants were asked to evaluate the simulator's usefulness for learning basic and advanced microsurgical skills, its suitability as an initial training model in microsurgery, and the necessity of its use before working with experimental animals. They also rated the ergonomic representation and realism of operative difficulty; the tactile sensation, hardness, and flexibility of the device materials; and its utility for maintaining microsurgery skills during periods without access to formal training. This comprehensive evaluation helped determine how well the simulator supports skill acquisition, retention, and preparation for real surgical scenarios from the perspective of the surgeons who used it.

Video assessment

The bundled pre- and post-course exercise videos, from both the slalom and tie-the-knot exercises, were anonymized, randomized, and evaluated independently by one experimental senior microsurgeon, one clinical senior microsurgeon (both with more than 10 years of experience) and one surgical resident, all using the Stanford Microsurgery Residents Training (SMaRT) scale[17] with 2 modifications: the authors considered the "Respect for Tissue" and the "Final Product" not applicable for this simulator because of the absence of adequate tubular structure to perform anastomoses. The SMaRT scale is one of the most widely used global rating scales for technical assessment in microsurgical training. It was published and validated in 2014 and has since been used in multiple studies. The duration each participant performed each exercise was calculated from the videos. The construct validity was based on this video assessment of the surgeons' performance using the simulator.

Statistical analysis

Statistical analyses were performed using GraphPad Prism software version 8.0 (GraphPad Software, San Diego, CA, USA). All parameters were first assessed for normality using the Shapiro-Wilk test, confirming that the data were normally distributed. Therefore, parametric tests were applied. Pre-course and post-course performances were compared using paired t-tests on the means of the scores obtained from the SMaRT scale. Scores were averaged from the evaluations of each trainee's pre-course and post-course video recordings. Ultimately, paired t-tests were used to evaluate the statistical significance of the pre-course vs. post-course performance scores. Statistical significance was set at a p-value < 0.05.

Figure 3 Microsurgery training setup: A) Setup used to perform microsurgical tasks under the microscope; B) Angle of the camera setup used to record the procedure, positioned to capture the detail of the Microsurgery Arena.

Results

Demographic characteristics

The demographics questionnaire was answered by 21 candidates: 15 men (71.4%) and 6 women (28.6%). Eighteen candidates were right-handed (85.7%), whereas only 3 were left-handed (14.3%). The average surgical experience was 4.3 years (range < 1 to 21 years, SD = 4.2 years). The microsurgical experience of the candidates is particularly noteworthy: 16 of 21 candidates (76.2%) had less than one year of microsurgical experience, whereas only 5 candidates (23.8%) had one year or more of experience in this field.

All the candidates were medical doctors. The candidates were attending the following surgical specialities: Urology,[1] Orthopaedics,[1] ENT,[1] Maxillofacial Surgery,[3] Plastic Surgery,[4] Vascular Surgery,[2] and Neurosurgery.[9]

Regarding lifestyle factors, 33.3% of candidates had played video games in the past, 28.6% still played, and 38.1% never played. The vast majority (95.2%) consumed less than 4 cups of coffee daily. The candidates came from various hospitals and countries, including Spain, Italy, Ecuador, Venezuela, and Bolivia, with training levels ranging from students to consultants.

Face validity

The realism and applicability of the experience to medical and surgical training were assessed with a seven-item questionnaire using a 5-point Likert usefulness scale.

Sixteen candidates (76.2%) found the device extremely useful for learning basic microsurgical skills, 4 (19.0%) found it very useful, and 1 (4.8%) found it somewhat useful. Twenty candidates (95.2%) found the device extremely useful or very useful as an initial training model in microsurgery. Regarding the ergonomic representation of the real operative difficulty, 8 candidates (38.1%) found it extremely useful, 12 (57.1%) found it very useful, and 1 (4.8%) found it somewhat useful. For maintaining microsurgical skills during periods without access to formal training, 8 candidates (38.1%) rated the device as extremely useful, 9 (42.9%) as very useful, 2 (9.5%) as somewhat useful, and 2 (9.5%) as not so useful. The device also received high marks for its utility in learning advanced microsurgical skills, with 12 candidates (57.1%) rating it as extremely useful, 6 (28.6%) as very useful, and 3 (14.3%) as somewhat useful. The importance of utilizing the device prior to transitioning to experimental animals was strongly highlighted, with 13 surgeons (61.9%) deeming this step extremely useful, 6 surgeons (28.6%)

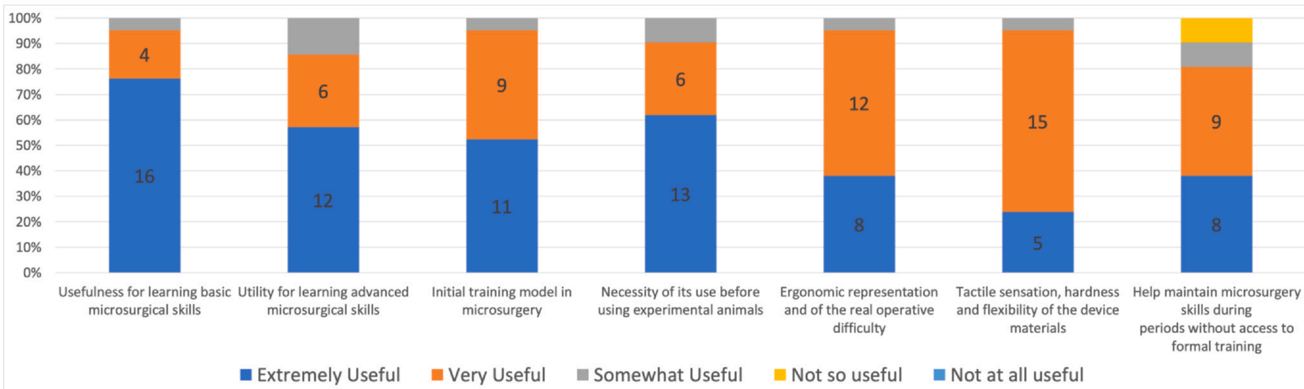

Figure 4 Face validity of the Microsurgery Arena. Categories include its effectiveness for learning basic and advanced microsurgical skills as an initial training model, the necessity of its use before animal experimentation, and its ergonomic and tactile representation of real operative conditions. It also evaluates the module's role in maintaining skills during periods without formal training. Responses are categorized as "Extremely Useful," "Very Useful," and "Somewhat Useful," indicating a generally positive reception across all aspects.

considering it very useful, and 2 surgeons (9.5%) rating it as somewhat useful.

The tactile sensation, hardness, and flexibility of the device materials were also well-received, with 5 candidates (23.8%) rating these aspects as extremely useful, 15 (71.4%) as very useful, and 1 (4.8%) as somewhat useful. Face validity results are shown in Figure 4.

Construct validity

After averaging the scores of all evaluators, the progression of students at the end of the course was established. Quantitative analysis of pre-course scores vs post-course scores showed a statistically significant improvement in all examined skills such as instrument handling, overall performance, efficacy, SMaRT scale score, operation flow, and time used to complete the tasks. Similarly, suture handling, quality of the knot, and suturing technique were improved; meanwhile, the time to perform the task was reduced after the course.

After averaging scores from all evaluators, a clear progression in student performance was observed at the end of the course. Quantitative analysis comparing pre-course and post-course scores revealed statistically significant improvements across all examined skills, including instrument handling, overall performance, efficacy, SMaRT scale scores, operation flow, and task completion time. Similarly, specific aspects such as suture handling, knot quality, and suturing technique showed marked improvement, accompanied by a significant reduction in the time required to complete tasks after the course (Figure 5).

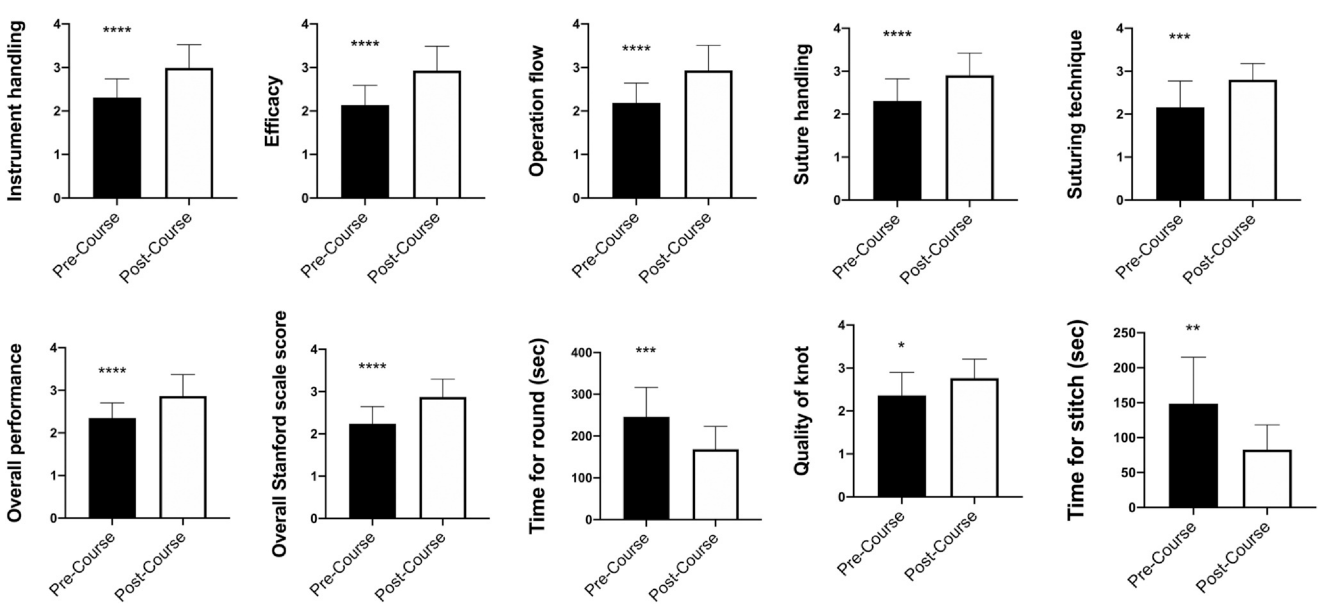

Figure 5 Quantitative assessment of microsurgical skill progression pre- and post-course. Bar graphs illustrate mean scores (± SD) for multiple parameters, including instrument handling, efficacy, operation flow, and SMaRT scale scores. Statistical analysis reveals significant improvements ($P < .05$) in most measured variables. Procedure times show a notable reduction, suggesting enhanced efficiency. These data indicate measurable advancements in microsurgical proficiency following training with the Microsurgery Arena.

Discussion

Despite the popularity of microsurgery in clinical practice, training criteria have not been standardized.[1,18] Surgical simulation plays an essential role in training and includes a range of living and non-living models, some of which have been used as objective assessment tools. Synthetic models in particular avoid ethical concerns, are portable, durable, and usable in any environment, enhancing their accessibility. Although synthetic microsurgical devices cannot replicate the full surgical experience of living models, they are invaluable for novice microsurgeons in mastering basic skills and shortening the steep learning curve.[2,19]

This study evaluated the Microsurgery Arena from multiple perspectives, focusing on both face validity and construct validity. Face validity was confirmed through positive feedback from trainees, who recognized the simulator's realistic tactile feedback and its usefulness as a preparatory tool before progressing to in vivo models, aligning with previous findings on synthetic simulators.[14] Training with synthetic materials has been shown to yield comparable outcomes for novices while significantly reducing live animal use and training costs.[4] Most participants rated the simulator as extremely or very useful in improving both basic and advanced microsurgical skills.

In terms of construct validity, we demonstrated significant improvements in key performance metrics, including instrument handling, suture quality, knot tying, and task completion time. These improvements were measured using the validated SMaRT scale, with pre- and post-course video assessments confirming measurable progress. This ability to produce reliable and reproducible data highlights the effectiveness of the Microsurgery Arena as an objective assessment tool. Moreover, performance assessments using the SMaRT scale revealed substantial skill improvements in areas such as hand dexterity, coordination, steadiness, and execution speed. This underscores the simulator's effectiveness not only as a training tool but also as a tool for evaluating microsurgical performance.

The combination of face and construct validity reinforces the dual functionality of the Microsurgery Arena. While it serves as a valuable training tool for isolating and practicing fundamental microsurgical tasks, it also provides a standardized platform for assessing skill acquisition. Trainees particularly appreciated how the device facilitated the transition from basic tasks to more complex scenarios, improving the reproducibility of successful outcomes in patients.

It is important to note that while the Microsurgery Arena may enhance specific microsurgical skills, the improvements observed in participants' performance were primarily attributed to the comprehensive microsurgical training course, with the simulator serving as a supplementary tool for practice and evaluation. It should be also acknowledged that the focus on basic tasks such as the slalom and tie-the-knot exercises may not fully represent more complex microsurgical skills such as vessel anastomosis. Future research could address this limitation by incorporating advanced suturing tasks and more realistic models to further validate the simulator's clinical relevance.

Evaluation by examiners highlighted discrepancies based on their level of experience, with the surgical resident evaluator assigning higher pre-course scores compared to experienced microsurgeons. However, consistent final evaluations across examiners suggest the Microsurgery Arena's exercises provided a standardized and objective basis for assessing progress. This standardization enables quantitative skill measurement and reinforces its role as an assessment tool.

Caffeine consumption was included in the demographic data due to its potential impact on microsurgical performance, as previous studies have indicated a link between caffeine intake and hand tremor.[20,21] However, no significant differences in performance were observed based on caffeine consumption, as most participants (95.2%) reported consuming less than 4 cups of coffee per day. This variable did not influence the results.

The evolution of surgical training toward simulation has fostered the development of synthetic microsurgical devices. These devices offer logistical, ethical, and economic advantages, making them indispensable for skill acquisition and maintenance during periods of reduced operative activity[2] but also for the development of new equipment useful in microsurgery.[22,23] The Microsurgery Arena meets the standards of an ideal synthetic simulator for microsurgical skill assessment, proving to be valid, reliable, and effective for post-course evaluations and long-term progress monitoring. Additionally, it may also provide an excellent platform for training fundamental microsurgical skills.

Conclusion

The growing ethical and logistical challenges in microsurgical training have made synthetic training devices indispensable for skill acquisition and maintenance. In this context, the Microsurgery Arena provides a promising tool for microsurgical training, enabling trainees to learn essential microsurgical skills in a controlled, reproducible environment while reducing the use of live animals for training. This work has proven that standardized exercises in the Microsurgery Arena can be consistently scored by different examiners, allowing precise tracking of skill progression. The face validity questionnaire reflected users' positive impressions of the device and their perception of its potential to improve microsurgical skills. Additionally, the construct validity assessment confirmed its ability to objectively evaluate technical performance. Therefore, the Microsurgery Arena proves to be a reliable tool for both advancing skills and providing consistent evaluation in microsurgery education.

Ethics statement

Ethical approval was not required for this study, as it did not involve human subjects, identifiable personal data, or animals.

Funding statement

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Conflict of interest statement

F. Costa and J. Srinivasan are the inventors of the Microsurgery Arena device described in this study and hold intellectual property rights related to this device. Dr. di Summa is an editor of *Journal of Plastic, Reconstructive & Aesthetic Surgery (JPRAS)*. The other authors declare no conflicts of interest. All authors affirm that there are no relationships that could inappropriately influence this work.

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