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Education

Randomized Controlled Trial: Acquisition of Basic Microsurgical Skills Through Smartphone Training Model

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Background: Microsurgery is essential in various surgical specialties, but learning these skills is challenging due to work hour limitations, patient safety concerns, documentation time, and ethical objections to practicing on live animals. This randomized controlled trial compares 2 microsurgical training models: the smartphone model and the microscope model.

Methods: Thirty students without prior microsurgery experience were randomized into 3 groups: control (CG), smartphone (SG), and microscope (MG). Participants performed microsurgical skill tests and a chicken femoral artery anastomosis before and after 10 hours of standardized training according to their assigned models. The CG performed the test twice without training. Performance was assessed by time to complete the anastomosis, University of Western Ontario Microsurgery Skills Assessment scale, anastomosis patency, and time to complete the round-the-clock test.

Results: No significant differences were observed among groups at baseline. Significant improvement in anastomosis time was achieved in the MG (27.4 minutes, $P = 0.005$) and SG (27.0 minutes, $P = 0.005$), but not in the CG (13.1 minutes, $P = 0.161$). On the University of Western Ontario scale, the MG improved by 6.0 points ($P = 0.002$), the SG by 5.1 points ($P = 0.006$), and the CG by 2.4 points ($P = 0.009$). Patency rate significantly improved in the MG and SG ($P = 0.002$) but not the CG ($P = 0.264$). Round-the-clock time improved in all groups ($P < 0.001$).

Conclusions: Basic microsurgical skills can be effectively learned using the smartphone training model, with performance improvements comparable to the microscope model. Its main limitation is the lack of stereoscopy. *(Plast Reconstr Surg Glob Open 2024; 12:e6403; doi: 10.1097/GOX.0000000000006403; Published online 20 December 2024.)*

INTRODUCTION

Microsurgery is an indispensable technique in many surgical specialties. However, the current training structure complicates the acquisition of fine motor skills required for microsurgery.[1] For a long time in surgical training, learning as an "apprentice" in the operating room has been a conventional approach to skill development.[2] This option is now less suitable owing to strict work hour limitations, an increased focus on patient safety, and the growing documentation time.[3,4]

Simulations in surgery training have proven effective in acquiring surgical skills and are currently used in several surgical specialties.[2,5–7] Simulation training in microsurgical courses is less accessible because of its high cost,

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significant time commitment, and increasing ethical objections concerning practicing on living animals.[1,8,9] Performing anastomoses in a skills laboratory with a surgical microscope is a common exercise for plastic surgery residents but is rarely feasible due to limited accessibility.[8,10] Consequently, there is a need for an alternative and validated training model that is accessible, inexpensive, ethical, and that enables students to efficiently acquire and maintain basic microsurgical skills.[11]

The best-validated nonliving training object is the microsurgical femoral artery anastomosis on a chicken thigh.[6,12] The digital revolution has ensured that almost everyone has a smartphone with a high-standard camera.[13] This allows us to zoom in on blood vessels and thus obtain a magnification of the surgical field that is comparable to that of a surgical microscope. This led to the idea of the smartphone setup, as already described by several authors.[8,13–19] The main advantages of this setup are accessibility, portability, and low cost, making it very useful for students and prospective microsurgeons when the availability of surgical microscopes is limited.[16] A smartphone model also allows for continuous practice, which is usually difficult with other training models owing to limited access to training facilities.[9] Therefore, it can be a valuable adjunct to microsurgical courses.[8,14] To the best of our knowledge, this is the first randomized controlled trial to compare the effectiveness of the smartphone model versus the conventional microscope model in acquiring basic microsurgical skills.

Takeaways

Question: How can basic microsurgical skills be effectively learned given the challenges of traditional training methods?

Findings: Our randomized controlled trial compared smartphone and microscope training models, showing that both achieved significant improvements in anastomosis time, University of Western Ontario Microsurgery Skills Assessment scores, and patency rates after 10 hours of training.

Meaning: Smartphone-based training can effectively teach basic microsurgical skills, offering an accessible alternative to traditional microscope training.

MATERIALS AND METHODS

Enrollment

Thirty medical master's students with no previous microsurgery experience were enrolled in our study and did not receive any remuneration. Every student had a smartphone with a camera capable of combining optical and digital zooms, producing a clear, in-focus image of the surgical field at 8–10× zoom. Before inclusion, all students were subjected to a basic surgical suturing test, during which they were instructed to perform 3 interrupted single sutures within 3 minutes. This was recorded and scored by 2 independent surgeons with a pass or fail. All medical students passed the test, and demographic data were collected through a questionnaire. All students received a 90-minute theoretical lesson on microsurgery followed by a step-by-step demonstration of end-to-end anastomosis of a chicken femoral artery. Figure 1 shows a schematic overview of our study protocol.

Randomization

The participants (n = 30) were randomized into 3 equal groups (n = 10) using a validated random number generator (www.randomizer.org)[5]: the microscope group (MG), the smartphone group (SG), and the control group (CG).

Test

All students were required to perform a baseline microsurgical skills assessment test using a microscope (WILD HEERBRUGG MTR 29). Standardized instrument sets (including 2 microsurgery forceps, a microsurgical needle holder, and microsurgical scissors) were provided to each student. Each student was given identical printed step-by-step instructions for the assessment test. Each student was instructed to watch a summary video of the microsurgical skills assessment test, which was discussed during the 90-minute theoretical lesson.

The baseline microsurgical skills assessment test consisted of 2 parts. The first part was the round-the-clock (RTC) exercise, a validated assessment tool for basic microsurgical skills.[20] Each student had to pass the needle of a nylon 9/0 suture through the eyes of 12 sewing needles placed in a clock pattern. The time to complete the exercise was recorded objectively, from picking up the needle to passing through the last needle eye.

The second part of the test involved anastomosis of the chicken femoral artery. The participants were instructed to use the back-wall-up method, as demonstrated during the theoretical lesson, and to perform at least 8 sutures. The maximum time allowed for this test was 90 minutes. The time to complete the anastomosis was objectively timed from picking up the needle to cutting the last suture. The test was filmed and scored by 2 independent microsurgeons using the University of Western Ontario Microsurgery Skills Assessment (UWOMSA) grading scale, a validated instrument for assessing microsurgical competence.[1,21] (**See figure, Supplemental Digital Content 1**, which displays the knot tying module, **http://links.lww.com/PRSGO/D715**.) The anastomosis was then checked for patency by injecting silicone glue into the lumen (Fig. 2).[22] The video recordings were obtained through the internal camera in the microscope. The recordings were limited to the surgical field, excluding audio, to prevent observer identification.

Smartphone and Microscope Training Setup

A commercially available phone holder was attached to the training table. The smartphone was secured to the holder and placed above the operative field, as shown in Figure 3. The smartphone camera function was used with 8–10× zoom. The focus was locked on the operative field until a clear and stable image was obtained. The same

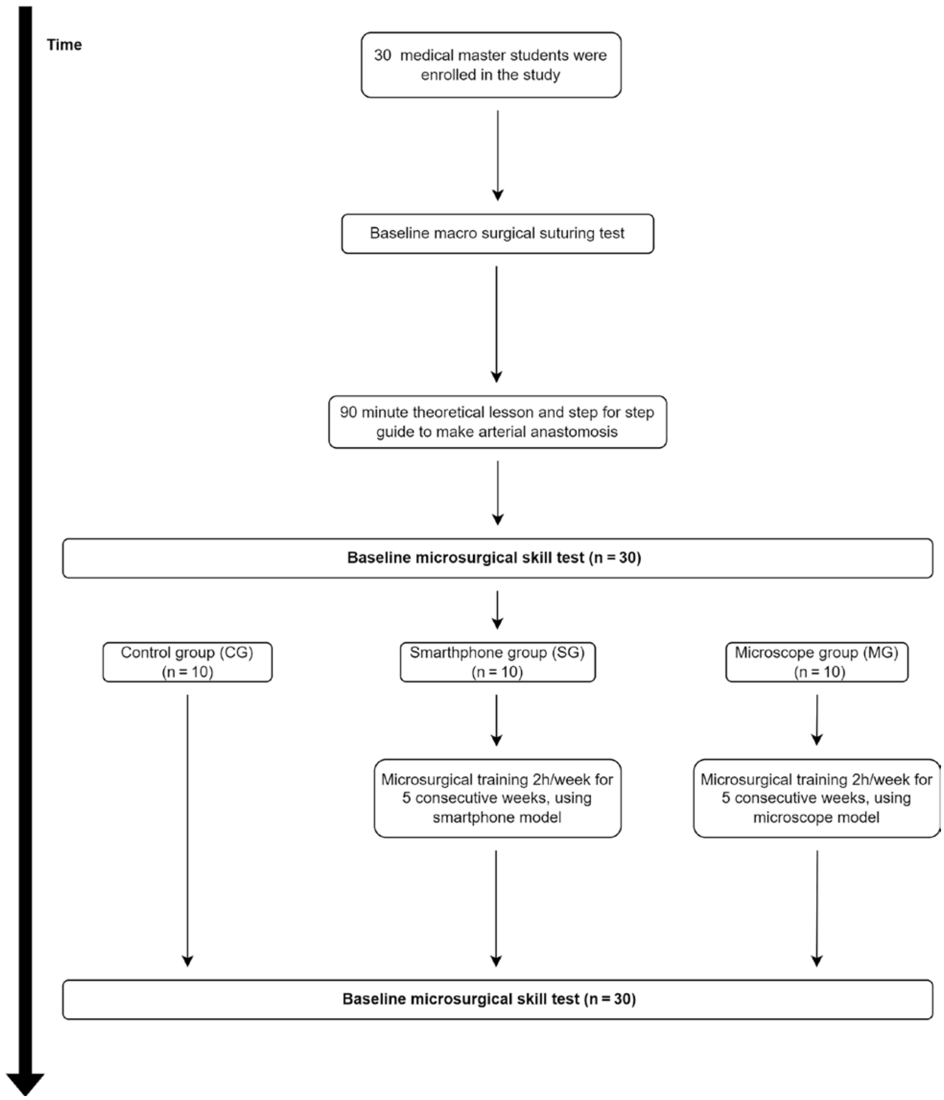

Fig. 1. Schematic overview of our study protocol.

microscope setup used to perform the baseline microsurgical skills test was used to train the MG (Fig. 4).

Training

The MG and SG received 10 hours of microsurgical training over 5 consecutive weeks. Students in the MG and SG completed a structured microsurgical practice program on the microscope or the smartphone, respectively. All 20 participants received a practical handout with exercises for each training day. Once the training phase of the study began, the students could only refer to the leaflet.

The program consisted of various exercises of increasing difficulty, as shown in Table 1. The first day was dedicated to becoming familiar with working under magnification through simple exercises such as scraping letters of a piece of paper with a 25G needle and lacing a gauze thread, as described by Demirseren.[23] Over the following 3 days, the tasks gradually became more complex, using only bench models with a high recommendation level, as Javid et al[12] reported. On training day 5, all students were instructed to perform an anastomosis of the chicken femoral artery.[12] The CG received no training and was not allowed to practice microsurgery during this period. After 5 weeks, the baseline microsurgical skills assessment test was repeated for all 3 study groups.

Sample Size and Statistical Analysis

The data were analyzed using the statistical software SPSS (version 28.0). The sample size calculation was based on an a priori power analysis. A minimum of 6–9 participants per group were required to observe a relevant reduction in anastomosis time of 30% with $\alpha = 0.05$ and power = 0.80, depending on SDs reported in other studies.[25,26] Therefore, we set up the study with 10 participants in each group.

The Kolmogorov–Smirnov test showed that continuous data were normally distributed. Analysis of variance was used to analyze normally distributed data. If a

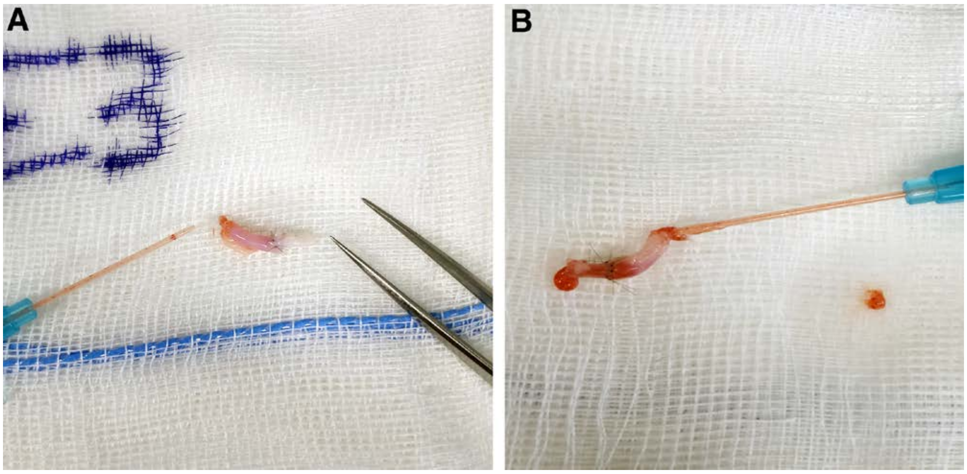

Fig. 2. Testing for anastomosis patency with a clear obstruction (A) and a patent vessel (B).

Fig. 3. Student practicing on the smartphone model.

Fig. 4. Student practicing on the microscope model.

significant difference between our 3 groups was observed, the data were further explored by a pairwise Tukey test, adjusting for multiple comparisons. The paired *t* test was used to assess the effect of the intervention within each group. Because of the small sample size, the results were double-checked with nonparametric alternatives: Kruskal-Wallis with Bonferroni correction for multiple tests and, if applicable, pairwise Wilcoxon signed-rank test. The outcomes are expressed as mean values and SD for normally distributed data and median and interquartile ranges for nonnormally distributed data.

Categorical data were analyzed using the Fisher exact test. Results were considered statistically significant at a *P* value of less than 0.05. Furthermore, we examined the interrater agreement between the 2 assessors by calculating the intraclass correlation coefficient, for which a value less than 0.5 indicates poor reliability, between 0.5 and 0.75 moderate reliability, between 0.75 and 0.9 good reliability, and any value greater than 0.9 indicates excellent reliability.[27]

RESULTS

A total of 30 medical students, 14 men and 16 women, successfully completed the study. The participants' ages spanned from 22 to 29 years, with a mean age of 24.2 years. The age and gender distribution across both groups demonstrated comparability, ensuring a balanced representation within the study cohorts (Table 2).

Time to Complete the RTC Test

Baseline data did not reveal differences among the 3 groups (Table 2; Fig. 5). The posttraining test was

Table 1. A Schematic Overview of the Microsurgical Tasks Day by Day

Day 1	Scraping letters of paper with a 25G needle Lacing a thread of gauze as described by Demirseren et al[23]
Day 2	RTC exercise[20] RTC exercise counterclockwise
Day 3	Simple microsurgical suturing on rubber glove model[24]
Day 4	Advanced microsurgical suturing on rubber glove model to simulate vessel wall suturing as described by Lahiri et al[24]
Day 5	Anastomosis of the femoral chicken artery[12]

significantly better in all 3 groups, with improvement within the MG by 3.0 minutes (SD = 1.5; $P < 0.001$), within the SG by 2.8 minutes (SD = 1.7; $P < 0.001$), and within the CG by 1.4 minutes (SD= 1.6; $P = 0.026$) (Fig. 5). Although a clear tendency was observed, the large SDs resulted in a statistically nonsignificant difference in improvement ($P = 0.065$).

After the intervention, pairwise comparison showed no significant difference between the performance of the MG (3.2 minutes , SD = 1.4) and the SG (2.7 minutes , SD = 1.3) ($P = 0.861$). The CG (5.8 minutes , SD = 2.3), however, performed significantly worse than the MG ($P = 0.007$) and the SG ($P = 0.002$) (Table 2; Fig. 5).

Time to Complete Chicken Femoral Artery Anastomosis

Because participants who failed to finish the task within the preset time of 90 minutes were given 90 minutes as their test result, the data were skewed to the right and not normally distributed. For this variable, nonparametric tests were applied.

The performance of the 3 groups was comparable at baseline ($P = 0.859$) (Table 2; Fig. 6). The median time for the MG was 65.6 minutes, with an interquartile range (IQR) of 56.2–90 minutes; for the SG, it was 66.9 minutes (IQR 55.8–90.0 minutes); and for the CG, it was 73.1 minutes (IQR 57.9–90.0 minutes). After the intervention, the MG had a median time of 43.9 minutes (IQR 37.3–48.7 minutes); the SG had a median time of 39.7 minutes (IQR 27.0–44.1 minutes); and the CG performed significantly worse, with a median time of 58.7 minutes (IQR 47.3; 90.0 minutes) ($P = 0.081$) (Fig. 6).

The MG demonstrated a significant median improvement of 27.4 minutes (IQR 15.9–30.8 minutes) ($P = 0.005$), as did the SG, improving by 27.0 minutes (IQR 19.6–46.2 minutes) ($P = 0.005$). The CG only improved by 13.1 minutes (IQR 0–41.2 minutes) ($P = 0.161$), which was not significant.

Among participants who failed within 90 minutes (nonfinishers), groups were comparable at baseline ($P = 1$), but the CG performed worse than the others after the intervention. The MG improved from 3 to 0 nonfinishers, the SG improved from 4 to 0 nonfinishers, and the CG improved only from 4 to 3 nonfinishers. Due to the limited sample size, this improvement was not significant ($P = 0.089$).

Microsurgical Skills Assessment (UWOMSA Score)

Two assessors rated each participant. As a measure of interrater agreement, the intraclass correlation coefficient was 0.82 (0.65–0.91), showing good reliability. Therefore, we report the mean UWOMSA score, which is the average of the scores of both assessors.

At baseline, all 3 groups were highly comparable (Table 2). Within groups, significant improvement was observed for the MG with 6 points (SD=4.0; $P = 0.002$), the SG with 5.1 points (SD = 4.9; $P = 0.006$), and the CG with 2.4 points (SD = 2.2, $P = 0.009$) (Fig. 7).

After the intervention, the CG scored significantly worse, with a mean of 12.2 points (SD=2.1), compared

Table 2. Study Results

	MG (n = 10)	SG (n = 10)	CG (n = 10)	*P*
Demographics				
Age (y), mean (SD)	23.9 (1.5)	24.1 (2.1)	24.5 (2.2)	0.854
Sex (male:female)	5:5	5:5	4:6	0.892
Pretraining				
RTC (min), mean (SD)	6.1 (1.6)	5.6 (2.3)	7.1 (2.4)	0.267*
Anastomosis time (min), median (Q1; Q3)	65.6 (56.2; 90.0)	66.9 (55.8; 90.0)	73.1 (57.9; 90.0)	0.859†
UWOMSA (points), mean (SD)	9.9 (2.9)	10.3 (3.3)	9.8 (1.9)	0.907*
Patency ratio	3/10	3/10	3/10	1‡
Anastomosis nonfinisher ratio	3/10	4/10	4/10	1‡
Posttraining				
RTC (min), mean (SD)	3.2 (1.4)	2.7 (1.3)	5.8 (2.3)	0.001*
Anastomosis time (min), median (Q1; Q3)	43.9 (37.3; 48.7)	39.7 (27.0; 44.1)	58.7 (47.3; 90.0)	0.007†
UWOMSA (points), mean (SD)	15.9 (2.1)	15.4 (3.8)	12.2 (2.2)	0.016*
Patency ratio	8/10	8/10	1/10	0.012‡
Anastomosis nonfinisher ratio	0/10	0/10	3/10	0.089‡

*Analysis of variance.
†Kruskal Wallis.
‡Fisher exact test.

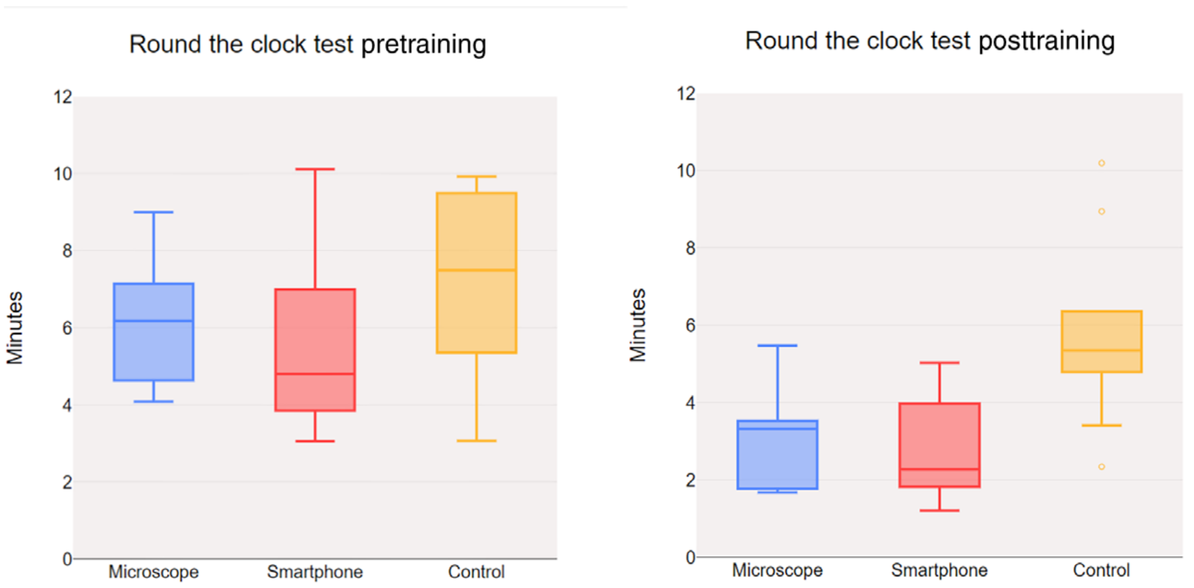

Fig. 5. Box plots of the time to complete the round-the-clock test pre- and posttraining (minimum, first quartile, median, third quartile, and maximum).

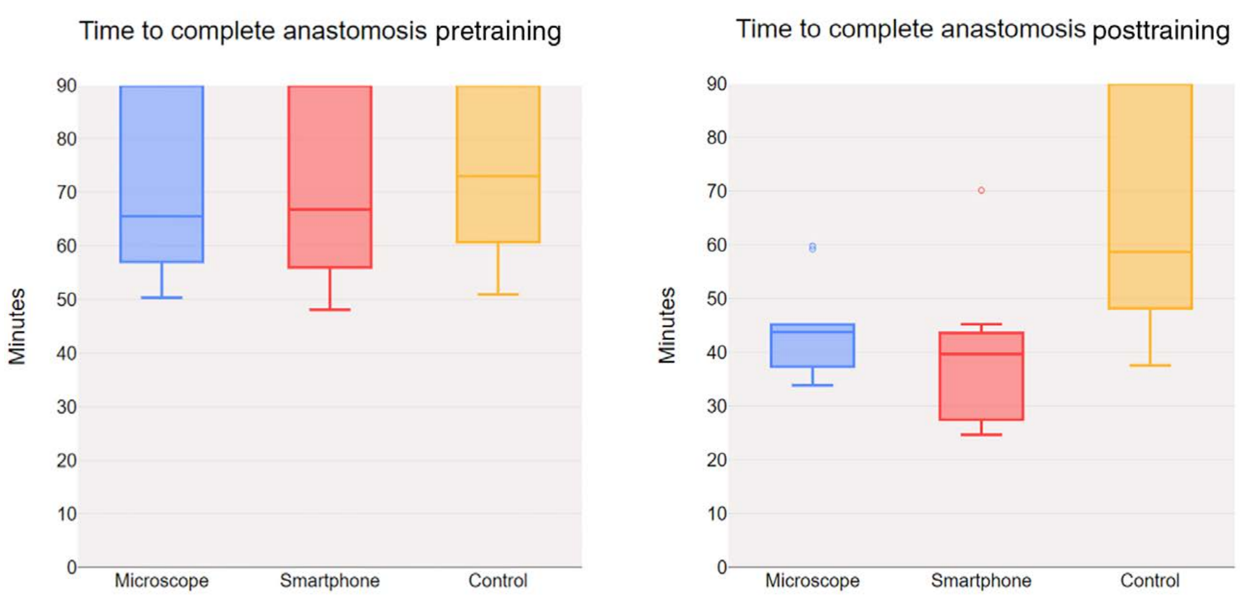

Fig. 6. Box plots of the time to complete the anastomosis pre- and posttraining (minimum, first quartile, median, third quartile, and maximum).

to the MG and the SG, who scored 15.9 points (SD=2.1; $P = 0.021$) and 15.4 points (SD=3.7; $P = 0.050$), respectively. Posttraining, there was no difference between the MG and SG ($P = 0.919$).

Patency

Patency rates increased from 3 of 10 to 8 of 10 in both the MG and SG. There was a slight decrease in patency in the CG from 3 of 10 pretraining to 2 of 10 posttraining. Although there was no difference between the groups at baseline ($P = 1$), the CG performed significantly worse than the training groups posttraining ($P = 0.012$).

DISCUSSION

Malik et al[25] previously highlighted the feasibility of acquiring basic microsurgical skills using an iPad. To the best of our knowledge, this study is the first randomized controlled trial to demonstrate the utility of the smartphone setup in acquiring basic microsurgical skills, with the observed learning curve closely aligning with that of the conventional microscope model.

Today, almost everyone owns a smartphone. The smartphone setup is low cost and can be assembled by purchasing a smartphone holder, basic microsurgery instruments, and a chicken thigh for less than $100.[8,28] The simulation is portable, lightweight, and can be installed in 5 minutes.[29] Using the smartphone as magnification allows for video recording during practice and objective video-based feedback from supervisors, live or later, with proven benefits.[25,30] The easily accessible setup allows consistent training in a controlled environment suitable for the trainee.[25] Video-based microsurgery also allows the addition of a second screen to watch and mimic microsurgery tutorials during training.

Conversely, several studies have suggested that performing a microsurgical anastomosis in a living model using a smartphone as magnification is challenging.[16,31] Their setup was slightly different from ours, and some obstacles to the smartphone setup should be addressed. As with conventional two-dimensional (2D) laparoscopy, the lack of stereoscopy is a limiting factor. However, this can be overcome by experience and secondary special depth cues to assess the position of the instruments in space.[31] The manipulation of instruments initially relied more on proprioception and subtle haptic feedback.[29] We found that students struggled with a lack of depth perception, resulting in complex eye-hand coordination for the first few hours, but once they adapted to this, their skill improved rapidly.[17]

Future smartphone development can lead to built-in cameras with improved optical zoom functions and possibly 3D capacity, enabling stereoscopy. This could further expand the scope of the smartphone setup.

This study aimed to demonstrate that fundamental microsurgical skills can be effectively acquired using a minimalistic and cost-effective setup. We observed no significant difference in the fluency or quality of the acquired skills between a conventional microscope and a smartphone-based setup. However, our primary focus is on the initial learning phase. It must address the attainment of the finesse, manual dexterity, and complex techniques needed for in vivo microsurgery. Our findings support smartphone-based training as a supplementary tool in microsurgical training.[19] Nevertheless, high-quality microsurgery courses remain indispensable for those aspiring to become proficient microsurgeons.

We observed a steep initial learning curve in our study. Despite the difference between the training groups and the CG, there was substantial progression after only a 2-hour training session using the microscope. This may suggest that becoming accustomed to operating under a microscope and handling the instruments constitutes a significant portion of the initial learning curve in microsurgery. Another notable aspect is that, even after undergoing 10 hours of training, some students within the training still display limited advancement in their microsurgical skills. This raises questions about individuals' inherent aptitude and potential to achieve proficiency in microsurgery.[32] Certainly, refined skills are just 1 facet of a microsurgeon's profession, yet they are indispensable.

Finally, several limitations should be acknowledged in our study. The 10-hour training duration is relatively brief, which may have minimized potential differences between the MG and SG. Additionally, although practicing an anastomosis on a chicken femoral artery offers a valuable simulation of in vivo microsurgery, it does not fully replicate the complexities of performing an actual anastomosis in the operating room.[6] Future studies could enhance their findings by surveying students posttraining to assess the impact of smartphone-based learning on their microsurgical performance in clinical settings. Finally, although patency was evaluated by injecting silicone through the lumen, this method provides limited

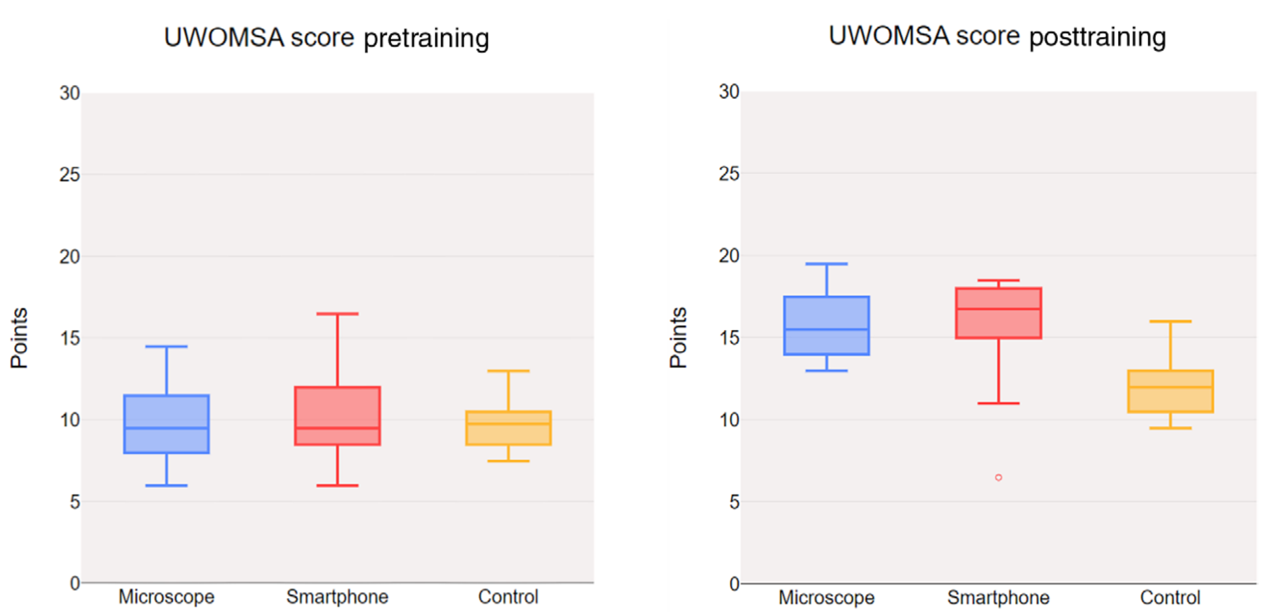

Fig. 7. Box plots of UWOMSA score pre- and posttraining (minimum, first quartile, median, third quartile, and maximum).

information regarding critical leakage at the anastomosis site and the integrity and continuity of the intima.

CONCLUSIONS

This study demonstrates that basic microsurgical skills can be learned effectively using a smartphone-based training model, showing performance improvements equivalent to the traditional microscope-based model. The main limitation of the smartphone setup is the absence of stereoscopy, which could potentially be addressed in the future using smartphones equipped with 3D cameras. The smartphone-based training model offers accessibility, portability, and cost-effectiveness, making it a valuable tool for students and aspiring microsurgeons. It can be integrated early into the training curriculum to help reduce the cost of microsurgical training or be an asset in regions with limited access to traditional microsurgery equipment. However, it should be noted that this study primarily focuses on initial skill acquisition, and high-quality microsurgery courses remain crucial for achieving advanced proficiency in microsurgery.

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DISCLOSURE

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

PATIENT CONSENT

Written informed consent was obtained from all participants in the study for participation and publication of photographs.

ETHICAL APPROVAL

The study was approved by the local ethics committee of the Antwerp University Hospital (20/15/706) and was carried out according to the Declaration of Helsinki.

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