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Alternative Magnification Devices for Microsurgical Training: Comparative Analysis

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ABSTRACT

AIM: To determine if low-cost magnification devices (USB computer microscope, smartphone) enable the acquisition and maintenance of basic microsurgical skills by comparing skills learned using these devices against those learned using a surgical microscope. Determining whether skills acquired using these devices can be transferred to the surgical microscope.

MATERIAL and METHODS: Twelve neurosurgical participants, ranging from faculty to postgraduate year-1 trainees, were randomly divided into three groups for training using a surgical microscope, smartphone, or USB microscope. All performed a pre-training evaluation for two surgical skills (round-the-clock suturing, anastomosis) using the surgical microscope, followed by 10 training exercises using only the assigned device. Upon completion, these tasks were evaluated again using the surgical microscope, and pre- and post-training exercise completion times and quality were compared.

RESULTS: Following training, the durations for pre- and post-training exercises, as well as quality, were compared. All groups significantly reduced the time to complete each task, and all groups significantly improved task completion quality. There were no significant differences in task quality or time to complete between the three groups, either pre- or post-training.

CONCLUSION: Microsurgical skills training using smartphones or USB microscopes enabled the acquisition and improvement of the examined microsurgical skills that were equivalent to skill improvement obtained by training with a surgical microscope. These acquired skills transferred from the low-cost magnification devices to the surgical microscope. Thus, training using smartphones and inexpensive USB microscopes can provide an affordable alternative for teaching and individual study to learn and maintain basic microsurgical skills, especially when access to operative microscopes are limited.

KEYWORDS: Microsurgery training, Simulation, Microscope, Smartphone, USB computer microscope

ABBREVIATIONS: **OR:** Operating room, **PGY:** Postgraduate year (from Medical School), **SAMS:** Structured assessment of microsurgical skills, **USB:** Universal service bus.

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INTRODUCTION

Neurosurgery requires extensive use of operative microscopes to perform microsurgical manipulations that include dissections, suturing, and anastomoses. Learning to perform these microsurgical tasks cannot be achieved with observation alone (32), but requires long days dedicated to training and practice (20,27,41).

In the last several years, the training of physicians in microsurgical techniques has increasingly relied on simulations, since this enables the repeated practice necessary to acquire these skills in safe and controlled environments, and long prior to any surgery on live patients (17). There are many types of simulation models. The most realistic simulations of clinical surgery include living animal models such as rats, animal tissues, and simulated surgery with cadaveric tissues (1). However, these "gold standard" models have ethical and economic issues that prevent their routine use (15,21), especially for training junior-level students. This has motivated the development of less realistic models to teach microsurgical skills. These include practicing suturing using surgical gauze (12), and latex gloves (4,33), and learning how to perform anastomoses using silicone tubing as model vessels (29).

Regardless of the microsurgical skills being taught, the trainee, by the definition of microsurgery, will require a microscope to learn these skills. Ideally this would be an operative stereo microscope, like that used to perform clinical surgery. However, these are expensive resources in any hospital or medical school, and in developing countries, the availability and accessibility of operative and even basic stereo microscopes (dissecting, inspection or Greenough microscopes) can be extremely limited (9). In such environments, surgical microscopes may only be located in the operating room and reserved for surgical procedures. So, how can one affordably provide trainees, and even more experienced surgeons, the opportunity to learn and practice microsurgical techniques away from the operating room, and on their own schedule? (2, 3,5,8,16,20,22,23,25,26,28,37).

The objective of this work is to evaluate the use of alternative magnification devices to enable trainees to acquire and improve basic microsurgical skills. In this study, we compare skills training using low-cost magnification microscope-like devices, specifically smartphones and a low-cost microscopes that attach to personal computer via a USB port or via a wireless Bluetooth link (USB scopes), against the gold-standard of clinical operating microscopes. We then examine if the microsurgical skills that were learned using smartphones and USB scopes can be transferred to the operating microscope.

MATERIAL and METHODS

This study examined using low-cost operating microscope replacement devices in a one semester microsurgical techniques training course for surgical residents and fellows. The overall organization of the study is shown in Figure 1. There were 12 participants in this study, who ranged in training from post graduate year one to five (PGY1-5), and also including a chief resident and a department of Neurological Surgery faculty member (Table I). Participants were randomly divided into 4-person groups (using Microsoft Excel RAND function) to examine microsurgical skills training using three different types of magnification providing devices, described below:

Operating microscope group (OR scope): For this group, all trainees used an OPMI Pentero 900 (Zeiss, Oberkochen, Germany) clinical surgical 3-dimensional (3D) microscope.

Smartphone camera group (Smartphone): This group used the backside camera from an iPhone (models 7, XR, and 11, Apple, Cupertino, CA, USA), with native iPhone camera software. The phone was attached to an inexpensive flexible support device (Figure 2A).

Table I: Study Participants. *Medical School Postgraduate Year (PGY)

Group	PGY or position	Gender	Age (Years)	Dominant hand
USB Microscope	1	Female	27	Right
USB Microscope	3	Male	29	Right
USB Microscope	5	Male	30	Right
USB Microscope	5	Male	30	Right
Smartphone	1	Female	25	Right
Smartphone	2	Female	29	Right
Smartphone	4	Male	29	Right
Smartphone	Faculty	Male	31	Right
OR Scope	2	Male	28	Right
OR Scope	3	Female	28	Left
OR Scope	4	Female	29	Right
OR Scope	Chief Resident	Female	30	Right

PGY: *Postgraduate year,* ***OR:*** *Operation room.*

USB microscope group (USB scope): This group used an inexpensive USB microscope that provided 50-1000X magnification (Wireless Digital Microscope, Skybasic, China), connected to a personal computer to carry out their practices (Figure 2B).

Prior to skills training, participants were provided with explanatory audio-visual materials on the principles of microsurgery and the exercises which they would carry out. These exercises, described below, are standard training methods used to impart basic skills at the beginning of microsurgical training, as well as to continue to perfect hand-eye coordination and instrument familiarization (6,10,18,24,34,38,42).

Program Description

The overall organization of the study is shown in Figure 1. The first program step was an initial pre-training evaluation. Having completed the first step, each participant then attended 10 training sessions over a 30 day period. Each training session lasted a minimum of 1 hour, with a maximum of 72 hours between sessions. Having concluded 10 training periods, a post-training evaluation was carried out. The evaluations and training activities were as follows:

Pre-Training Evaluations

All participants, regardless of the group to which they were assigned, first performed the following two exercises using a Zeiss OPMI Pentero 900 surgical microscope.

1. Round-the-Clock: This exercise consists of threading a single nylon 8-0 suture consecutively through twelve needles arranged in a 3,4 cm diameter clock-shape circle (Figure 3A). Right-handed participants typically complete the exercise clockwise, while left-handed participants generally carry out the exercise counter-clockwise. The time to complete the path was measured, as well as the quality, as measured using a Global Rating Scale "GRS" modified from Assessment of Microsurgical Skills "SAMS" (7) criteria including proper instrument use, user stability and final quality (Table II).

2. End-to-end Anastomosis: This exercise is to perform an end-to-end anastomosis on 2 mm diameter silicone vessels using nylon 10-0 sutures (Figure 3B). The time needed to complete suturing was measured and the final quality of the product was then scored using a "GRS" modified from "SAMS" (7) (Table III).

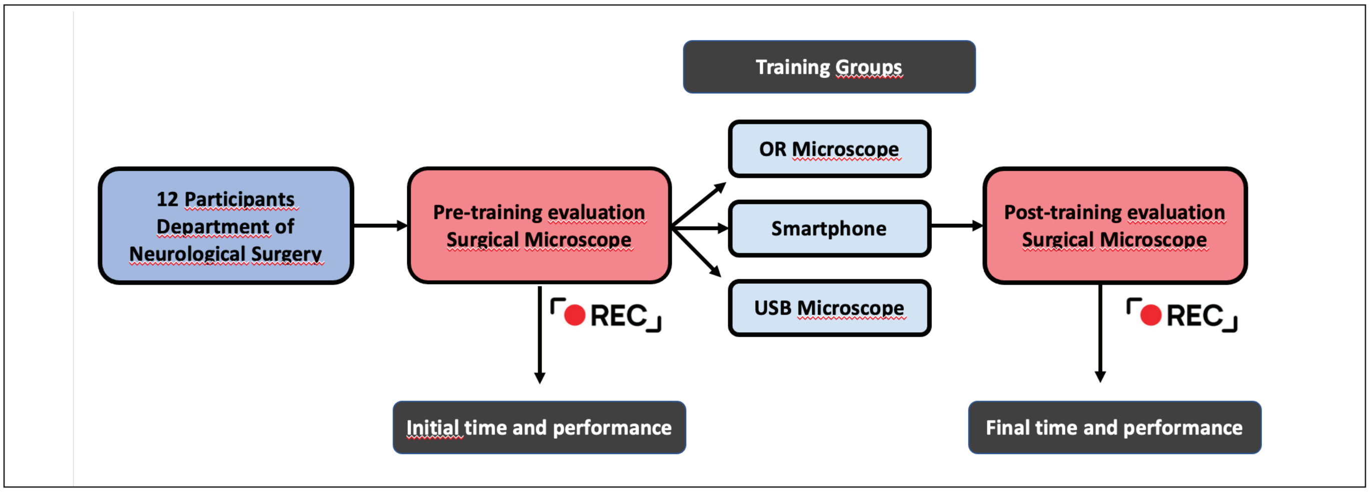

Figure 1: Study organization flow chart.

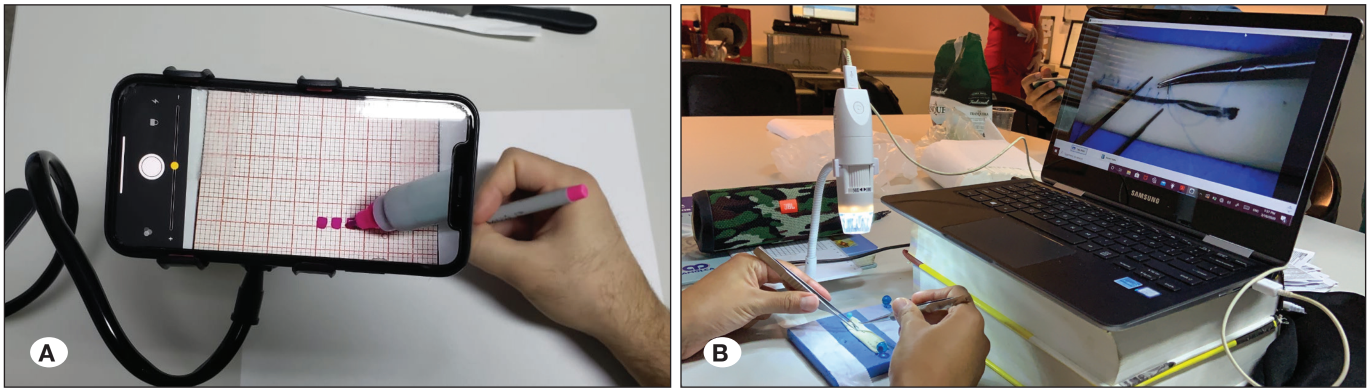

Figure 2: Alternative "microscope" imaging devices: **A)** Smartphone attached to a support. **B)** USB microscope connected to a personal computer.

Training Sessions 1-5

For these training exercises, each participant used their assigned magnification devices (OR scope, smartphone, USB scope), to carry out the following exercises 10 times, for a minimum of 1 hour each training session, over a 30-day period as described above.

1. Micro Grids: This warmup exercise is to colour in as many 2x2mm squares as possible in 30 seconds in a 5x5 cm segment of an electrocardiogram strip. Each 2x2 square must be fully and carefully coloured, with at least one blank square in between consecutive coloured-in squares (Figure 4A).

2. Stitch on Latex: This exercise is to approximate a 3 cm long slit cut in a latex glove that is slightly stretched across a collecting jar lid. Users make five separated 7-0 polypropylene stitches. Each stitch must be meticulous, and the knots must be equidistant (Figure 4B).

Training Sessions 6-10

Each participant used their assigned magnification devices to carry out these two new higher complexity exercises 10 times, for a minimum of 1 hour for each training session, over a 30-day period.

3. Drainage Suture: The participants approximated a 2.5 cm long incision cut along the major axis of a Penrose drain using continuous 8-0 polypropylene stitches (Figure 4C). This task is more difficult than the latex stitch, since the back wall of the drain tube must not be involved in the stitch.

4. Grape Dissection: This exercise was to perform a meticulous dissection of a star drawn on the surface of a grape, using an ophthalmic knife and forceps, trying to remove only the skin without damaging the pulp (Figure 4D).

Post-training evaluation

Using the OR scope once again, participants repeated the pre-training evaluation exercises, specifically Round-the-clock and End-to-End Anastomosis, which were again video recorded. The videos of the pre-training and post-training evaluations were then examined blindly by an expert neurosurgeon who is blind to participants and their training methods quantified using a “GRS” modified from the “SAMS” (7). Scoring criteria are provided in Tables II and III.

Once the training exercises concluded, each participant then completed an anonymous satisfaction survey about the utility of the programme (Table IV).

Table II: Scoring the Round-the-Clock Exercise. Scoring is Graded from 1 to 5. Scoring Rubric is Modified from the SAMS Scoring Criteria (32)

		Scoring				
		1	**2**	**3**	**4**	**5**
Dexterity	**Stability**	Frequent tremor		Occasional tremor		No tremor
	Use of instruments	Awkward moves due to inappropriate use		Occasional awkward moves		Fluid movements
Operative Flow	**Continuity of steps**	Frequently stopped, unsure of next move		Reasonable progression		Effortless flow from one move to the next
	Movement	Unnecessary and repetitive moves		Efficient but with some unnecessary moves		Economy of motion and maximum efficiency
	Velocity	Excessive time used for each step		Efficient time		Excellent speed and superior dexterity
Total Score						/25
Time to Complete						

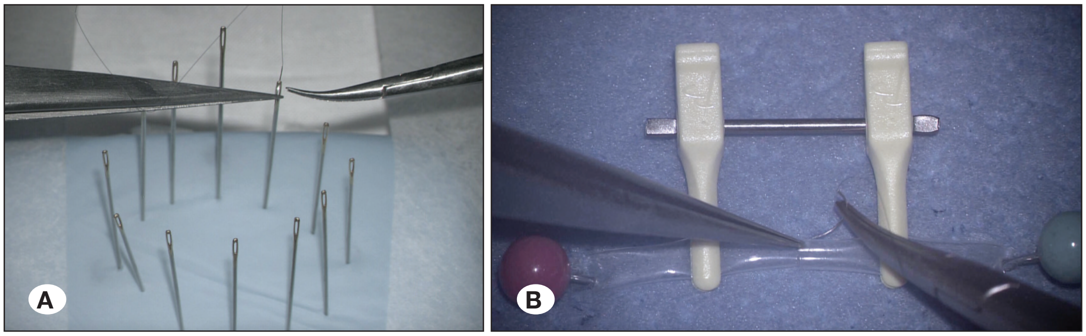

Figure 3: Evaluation exercises: **A)** Round-the-Clock with nylon 8-0 suture. **B)** End-to-End anastomosis of 2 mm diameter silicone vessels using nylon 10-0 sutures.

Table III: Scoring the End-to-End Anastomosis Exercise. Scoring is Graded from 1 to 5. Scoring Rubric is Modified from the SAMS Scoring Criteria (32)

		Scoring				
		1	**2**	**3**	**4**	**5**
Dexterity	**Steadiness**	Frequent tremor		Occasional tremor		No tremor
	Instrument handling	Awkward moves due to inappropriate use		Occasional awkward moves		Fluid movements
Visual-Spatial Ability	**Suture placement**	Frequently lost sutures and uneven placement		Occasional uneven suture placement		Correct suture placement
	Knot technique	Insecure knots		Secure knots with awkward movement		Correct knot technique
Operative Flow	**Steps**	Frequently stopped, unsure of next move		Reasonable progression		Effortless flow from one move to the next
	Motion	Unnecessary and repetitive moves		Efficent with some unnecessary moves		Economy of motion and maximum efficiency
	Speed	Excessive time used for each step		Efficient time		Excellent speed and superior dexterity
Patency Testing		Leak				Patent, no leaking
Total Score						/40
Time to Complete						

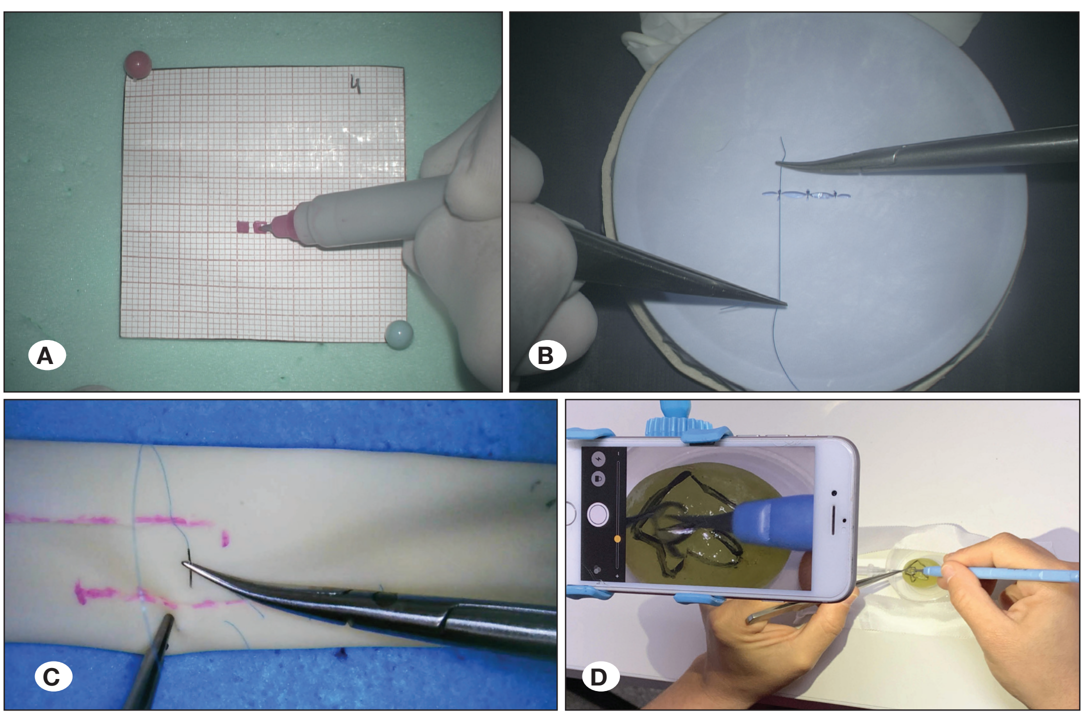

Figure 4: Training exercises: **A)** Micro grid colouring. **B)** Stitch on latex to approximate an incision using 7-0 polypropylene. **C)** Drainage Suture; to approximate an incision with continuous 8-0 polypropylene stitches on a Penrose drain. **D)** Grape Dissection; to excise star-shape segment of grape skin, shown here being performed using a smartphone.

Statistics

Statistical analyses of time and quality were made using the Kruskal-Wallis test for non-parametric variables and the Sign test for paired data, using Stata software version 14.0 (StataCorp LLC). Interquartile ranges (IQR) were also calculated for these comparisons, and for graphing display.

RESULTS

The time that participants required to complete the round-the-clock and the end-to-end anastomosis exercises were registered, as was the quality of their work.

Round-the-clock

For the pre-training "round-the-clock" task, there were no significant differences in time to completion (p=0.68) between the three imaging device groups (Figure 5). The OR scope group completed this exercise with a median of 323 seconds (IQR 242" - 361"). The Smartphone group times were 226 seconds (IQR 175"-371"), while the USB scope group median was 304 seconds (IQR 221" - 333").

After training, all participants significantly reduced their time to completion (p=0.006), cutting times nearly in half, from 284 seconds (IQR 197"- 346") before training, to 152 seconds

Table IV: Post-training Satisfaction Survey

Magnification Device: ____

Instructions: Indicate your level of satisfaction.

Parameters for Evaluation	Extremely unsatisfied	Unsatisfied	Neutral	Satisfied	Extremely Satisfied
Definition of the objectives of the training					
Introductory lectures and materials distributed					
Exercises used					
Participation and interaction with the tutor					
Time allotted for training					
Facilities					
Overall satisfaction					

Please answer these questions:

1. What did you like about the training program?
2. What aspects could be improved?
3. Do you think that this training could benefit you in your daily practice? If your answer is affirmative, please provide details:
4. Please feel free to share any additional comments or thoughts:

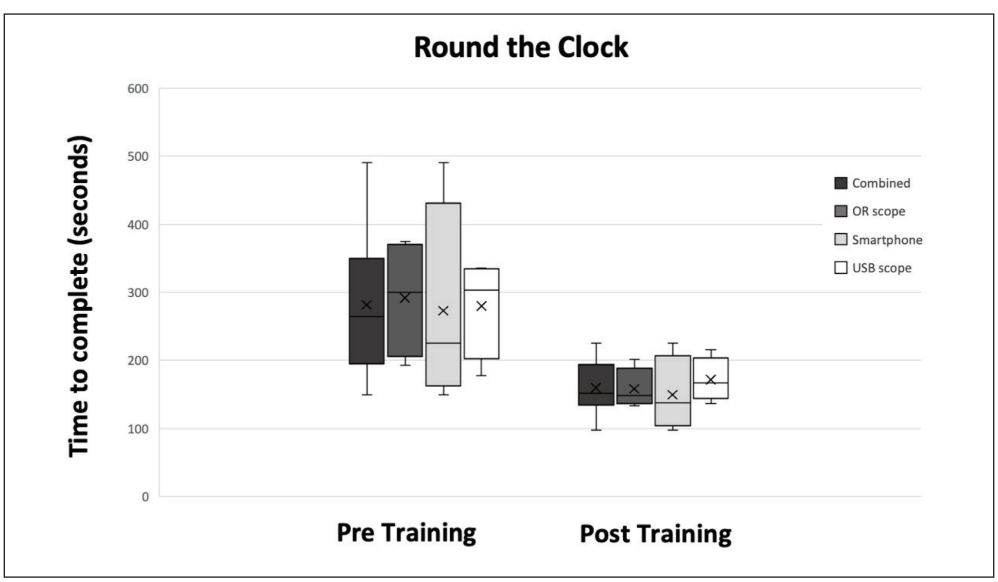

Figure 5: Time to complete exercise before and after training for all groups combined, and for each separate magnification device group: Box plots show median, 25th and 75th centiles, and full range (whiskers). X indicates mean. *Completion time for combined groups was reduced after training.

(IQR 135” - 190”) after training (Figure 5). There were no significant differences between the groups after training (p=0.58). The OR scope group carried out the exercises in 149 seconds (141” – 176”), the Smartphone group in 137 seconds (109” - 197”), and the USB scope group in 173 seconds (152” - 197”).

The quality metric for performing this exercise, for all groups combined, significantly increased from a mean score of 12/25 (12 out of 25) before training, to 18/25 after training (p=0.04) (Figure 6). There were no significant differences in quality between the three groups prior to training (p=0.58). The pre-training score for the OR scope group was 11/25, while the pretraining scores for the Smartphone and USB groups were 13/25 and 12/25, respectively. The post training scores for the three groups were 19/25, 17/25 and 16/25, for the OR, smartphone and USB groups, respectively, and there was no significant differences between these groups (p=0.34).

End-to-End Anastomosis

For the pre-training anastomosis task, there was no significant differences in completion time (p=0.79) between the three groups (Figure 7). The median times for the OR scope group to complete the anastomosis was 1904 seconds (IQR 1210”- 2257”)), while the Smartphone and USB groups took 1781 seconds (IQR 1067”- 2685”), and 2310 seconds (IQR 1538”- 2813”), respectively.

After training, the combined times for all groups to complete the anastomosis was significantly reduced (p=0.0005), with a median reduction from 2002 seconds (IQR 1318”- 2512”) before training to 846 seconds (IQR 726” - 1395”) after training (Figure 7). The completion times between the three groups were not significantly different post-training (p=0.47), albeit the ranges varied between them (Figure 7). The median (and range) for the post-training time to complete the anastomosis

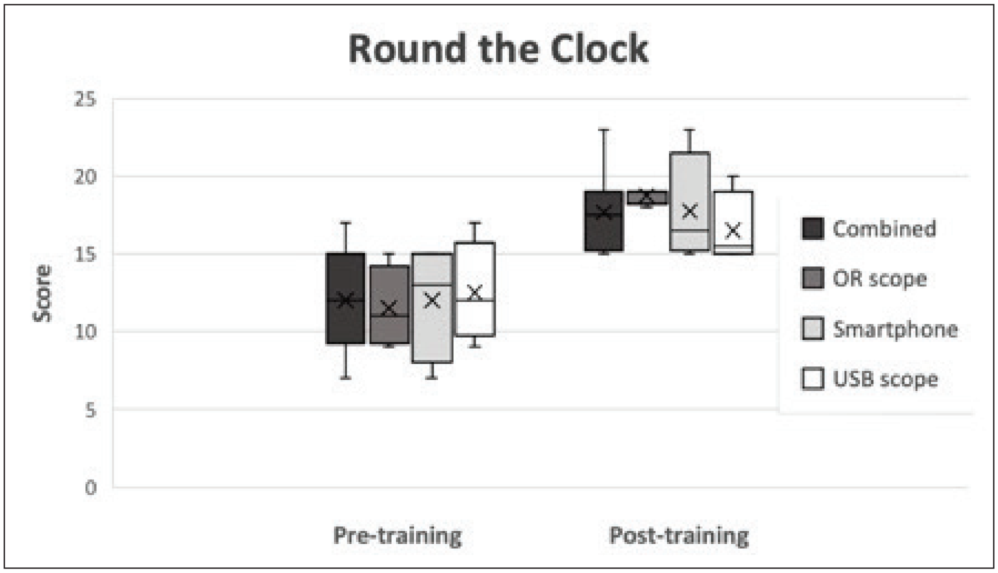

Figure 6: Quality score for exercise before and after training for all groups combined, and for each separate device group.

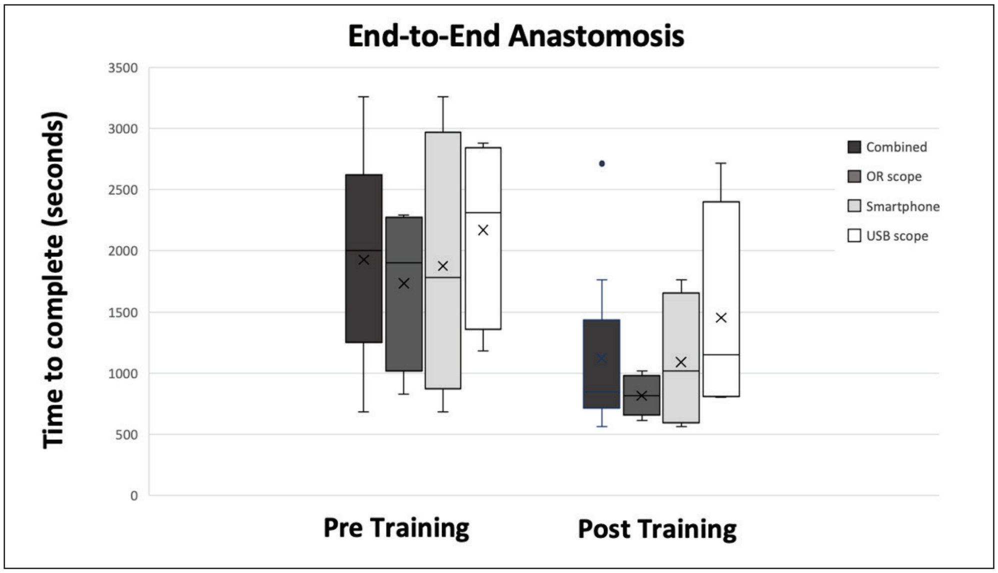

Figure 7: Times to complete end-to-end anastomosis exercise before and after training for all groups combined, and for each separate device group.

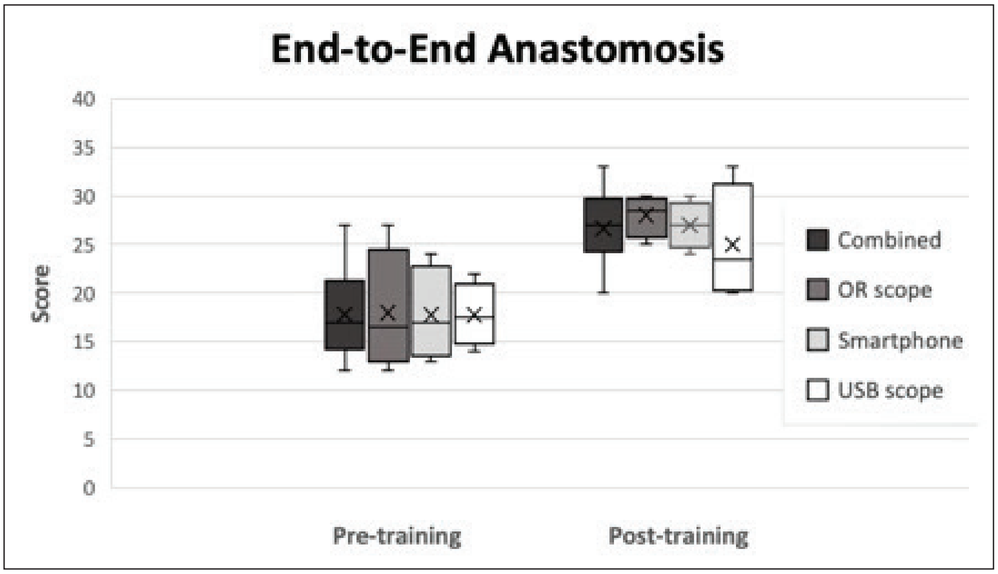

Figure 8: Quality scores for exercise before and after training for all groups combined, and for each separate device group.

was was 817 seconds (IQR 695" - 938") for the OR scope, and 1018 seconds (IQR 630" - 1550") and 1143 seconds (IQR 819" - 2684") for the smartphone and USB scopes.

The quality metric evaluation, for all groups combined, significantly increased from a mean score of 17/40 before training, to 27/40 after training (p=0.005) (Figure 8). Before training, there were no significant differences in quality between the three groups (p=0.95), with scores of 16/40, 17/40 and 18/40 for the OR, Smartphone and USB scopes. Similarly, there were no significant differences between the three groups post training (p=0.73), with individual group scores of 28/40, 27/40, and 26/40 for OR, Smartphone and USB scopes.

The participant-completed anonymous post training satisfaction surveys indicated that 91.6% (11/12) were satisfied or very satisfied with the training objectives, while 8.4% rated the objectives/exercises as neutral, and 100% were satisfied or very satisfied with how the training improving their surgical skills. Participants in the smartphone and USB groups noted in comments that they appreciated that the exercises enabled their freedom of choice as to when and where to practice. 91.6% indicated that the program increased their confidence for when they face new procedures in the operating room (Table IV).

DISCUSSION

Achieving and maintaining the microsurgical skills needed to calmly, confidently, and safely perform neurological surgeries requires considerable training and ongoing practice (36). It particular, it has been shown that ongoing training provides superior knowledge and motor skills retention than training carried out in intensive courses (13,14,17,30). However, ongoing training or practice is often not feasible due to the lack of necessary infrastructure, which includes a suitable microscope (11,20). To provide a microscope alternative for microsurgical training, Kim et al. described the use of a smartphone (25). In turn, several other reports also examined using smartphones and similar devices, and concluded that these could be used to enable the acquisition of basic skills during the initial stages of learning (2,3,5,8,16,20, 22,23,26,28,37). Among the advantages reported, are that such devices are ubiquitous and they can enable study outside normal working hours and away from the operating room (3,5). In addition, recorded practices can be evaluated by a tutor, with the aim of correcting mistakes and improving techniques (3,5,28).

In this report, we provide the first description that we are aware of, for using inexpensive USB personal computer microscopes for microsurgical training. These devices have found widespread use in many disciplines, including in dermatology and otorhinolaryngology (11,19,31,35). Suitable USB microscopes can be purchased for less than $50 USA. These easily connect to both Mac and Windows personal computers via a USB port, while other models can connect to computers and tablets via wireless Bluetooth. These typically provide magnifications from 20X to 200X, include integral LED lighting, and an integral or optional adjustable stand. In the model used in this study, the pixel density was 2MP (megapixels), which we found to provide sufficient resolution.

The principle limitation of smartphones and USB microscopes for microsurgical training, is that these do not provide stereoscopic vision or depth perception, unlike surgical and other stereo microscopes (variously referred to as dissecting, 3D, inspection, or Greenough microscopes). The absence of stereopsis adds some training difficulty, especially at the beginning. However, after practice, this is sufficiently compensated for by proprioception, and by physical contact between forceps, sutures, and other exercise elements. Image resolution and contrast with OP scope are better compared with smartphones and USB scopes. although these alternative devices provide sufficient resolution and contrast for training. However, image lag time or refresh latency can be somewhat problematic with both USB microscopes and smartphones. Despite that, most students rapidly adjust to refresh latencies with practice. It should be noted that refresh latency delays can be minimized with bright lighting, and that these devices continue to improve.

As described in multiple reports using smartphones, after an initial learning period, participants rapidly improve their skills and speed (26,28). Similarly, in the present study, we found that our training program was highly successful. This was demonstrated by significantly reducing the time to complete tasks by approximately one half, while also significantly increasing quality (Figures 5-8). What was striking, is that there were no significant differences in skill or speed improvement between between the OR scope, smartphone, and USB microscope groups (Figure 5 and 7).

Since all three groups were statistically equal in enabling skills development, this suggests that the lack of stereopsis during training for the smartphone and USB microscope groups had no substantial effect on skill acquisition. Thus, for these basic microsurgical skills, training with alternative magnification devices appears to be comparable to conventional training using the surgical microscope. Since the final tests were done using the OR surgical microscope, this allows us to infer that the acquired skills were readily transferred to the surgical microscope. This is in contrast to the report by Wher and Held (39), where it was reported that participant who trained with stereoscopic vision devices performed superiorly than those that used monoscopic vision devices.

As the main limitation of our study, the limited number of participants did not allow us to compare the efficiency of both alternative magnification devices with each other. We believe that this work could lay the foundations for the development of a new study on a larger scale, that allows to elucidate which alternative device is most effective for microsurgical training.

All participants, regardless of imaging device group, reported in the anonymous post-training satisfaction survey, that they were satisfied or very satisfied with the training programme, as this enabled them to improve their microsurgical skills. Additionally, 100% of participants expressed that they will continue using these exercises, with smartphone or USB scopes, to maintain and improve their skills. In accordance with that, all participants indicated that they felt more secure and confident to address microsurgical procedures after completing the training.

CONCLUSION

Smartphone and USB microscope training enables the acquisition and improvement of basic microsurgical skills that is comparable to training using a surgical microscope. These newly acquired or improved skills were then transferable to the surgical microscope. Thus, inexpensive USB microscopes and ubiquitous smartphones provide a highly available option for microsurgical skills training and practice, that is especially valuable when access to OR or stereo microscopes is limited.

Declarations

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. The authors declare that there are no conflicts of interest.

Availability of data and materials: The data used to support the findings of this study are available from the corresponding author upon reasonable request.

Disclosure: The authors declare that there is no conflict of interest.

AUTHORSHIP CONTRIBUTION

Study conception and design: SEF, FCG, ATG

Data collection: SEF, FCG, JFD, CM

Analysis and interpretation of results: SEF, HD, PAR

Draft manuscript preparation: SEF, FCG, MKB, GS

Critical revision of the article: FCG, MKB, GS

Other (study supervision, fundings, materials, etc...): PAR, MN, JFD

All authors (SEF, ATG, JFD, FCG, CM, MN, HD, SG, PAR, MKB) reviewed the results and approved the final version of the manuscript.

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