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Utilization of a 3D Printed Simulation Training Model to Improve Microsurgical Training

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Background: Simulation is integral to the development and maintenance of microsurgical skills. Several simulation models have been described ranging from benchtop to live animal models. High fidelity models are often burdened by cost and ethical issues limiting widespread implementation. This study aims to determine the feasibility of a microsurgical training platform using the Konjac noodle model.
Methods: A prospective cohort study was conducted at our institution. A progressive microsurgical training curriculum was developed. A bespoke three-dimensional printed training platform was produced to enable residents to record training and assessment tasks. Microsurgical skills were blindly assessed before and after completing the training program using the University of Western Ontario Microsurgical Skills Assessment instrument.
Results: Plastic surgery residents at various stages of training were recruited (n = 10). A significant improvement in vessel preparation from a pre-training median of 3 (IQR 2 -4) versus a post-training of 4 (IQR 3 -5, $P = 0.0035$) and suturing with a pre-training median of 3 (IQR 2 -4) versus a post-training of 4 (IQR 3 -5, $P = 0.0047$) domains of the University of Western Ontario Microsurgical Skills Assessment score was demonstrated after completion of the training program. There was a significant improvement in the global rating score (3 ± 1 versus 5 ± 1, $P = 0.0045$). Participants felt more confident performing a microsurgical anastomosis following the training program.
Conclusion: The use of the Konjac noodle model and video-based assessment using a three-dimensional printed model is an effective teaching tool that improves resident's microsurgical skills. *(Plast Reconstr Surg Glob Open 2023; 11:e4898; doi: 10.1097/GOX.0000000000004898; Published online 3 April 2023.)*

INTRODUCTION

Simulation has been integral to the development and maintenance of microsurgical skills. The scope for in-theatre development of microsurgical skill has significantly reduced in recent years owing to restricted working hours, rotational training patterns, increased administrative burden, medicolegal concerns, and reduced resident autonomy.[1] These changes have been compounded by limited operating during the cornoavirus 2019 pandemic, which has resulted in trainers and trainees alike revisiting the option of simulation-based microsurgical training.[2,3] Simulation-based microsurgical training has thus never been more relevant.

Several microsurgical simulation models have been described, ranging from synthetic materials to animal models and more latterly, to virtual reality.[4,5] Each simulation model has inherent advantages and disadvantages that preclude widespread use. Models using synthetic materials such as urinary catheters and latex gloves are low cost and easily accessible although lack face validity. Human and animal cadaveric models have been described although ethical implications and availability preclude routine use. The "live" rodent femoral artery model is often considered the gold standard in the development of microsurgical skill,[6,7] but once again, ethical,

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financial, and logistical issues related to maintenance of high levels of animal husbandry and welfare limit routine use.

The Konjac noodle model has attracted interest over recent years as a low-cost, high-fidelity model for microvascular anastomosis that avoids the ethical implications of using organic tissue.[8] The Konjac noodle is readily available and has a long shelf life, making it an attractive alternative to conventional models for the acquisition of microsurgical skills (200 g/0.5 GBP/0.6 USD~5000 anastomosis).

Alongside a high-fidelity model, there exists a need for measurable and reproducible methods of assessment.[9] The demands of service provision and associated time constraints placed upon attendings limit widespread adoption of the apprenticeship model of direct observation and real-time feedback.[10] Advances in mobile technology offer potential to address these limitations through provision of timely, objective and actionable feedback during microsurgical skill acquisition and refinement.

This study aimed to determine feasibility of using a three-dimensional (3D) printed microsurgical training model using the Konjac noodle to simulate microvascular anastomosis and to evaluate the impact of a digital assessment and feedback platform on the development of microsurgical skills.

Takeaways

Question: Does a progressive microsurgical training curriculum with the use of a microsurgical training platform and Konjac noodles improve plastic surgery resident's skills?

Findings: A bespoke three-dimensional printed training platform was produced to enable residents to record training and assessment tasks. Microsurgical skills were blindly assessed before and after completing the training program using the University of Western Ontario Microsurgical Skills Assessment instrument. A significant improvement in skills was demonstrated following completion of the training program.

Meaning: We have demonstrated that a structured progressive microsurgical training program with an innovative three-dimensional printed simulator leads to measurable and significant improvements in microsurgical skill.

MATERIALS AND METHODS

Platform Design and Characteristics

A stereolithography file (.stl) of the microsurgical platform was designed on Autodesk's Fusion 360 software (Autodesk, San Francisco, Calif.) and manufactured on a commercial Fusion Deposition Modelling Ender 5 3D printer (Creality, Shenzhen China) in Polylactic Acid (PLA) sourced from RS UK (1.75 mm filament by RS, Northants, UK). The construct required 50 g of PLA material and 70 minutes of printing time. The device was designed incorporating the "round the clock" exercise for early stage trainees as well as the rib simulator for advanced level trainees. (Fig. 1) The flexibility provided by 3D-printing technologies was key for the development of this low-cost platform.

Study Design and Participants

A prospective single center cohort study was conducted at our institution. Plastic surgery residents from postgraduate years 1 through 6 were identified and recruited through open advertisement within our department. All study participants were provided with a 3D-printed microsurgical training model. Simulated microvascular anastomosis was performed using Konjac flour noodles. Participants' smartphones were mounted on a bespoke training platform and used to record simulated anastomosis for assessment. All microsurgical tasks were completed under 10x magnification standard microsurgical instruments (Mercian, UK) and an 8-0 monofilament suture

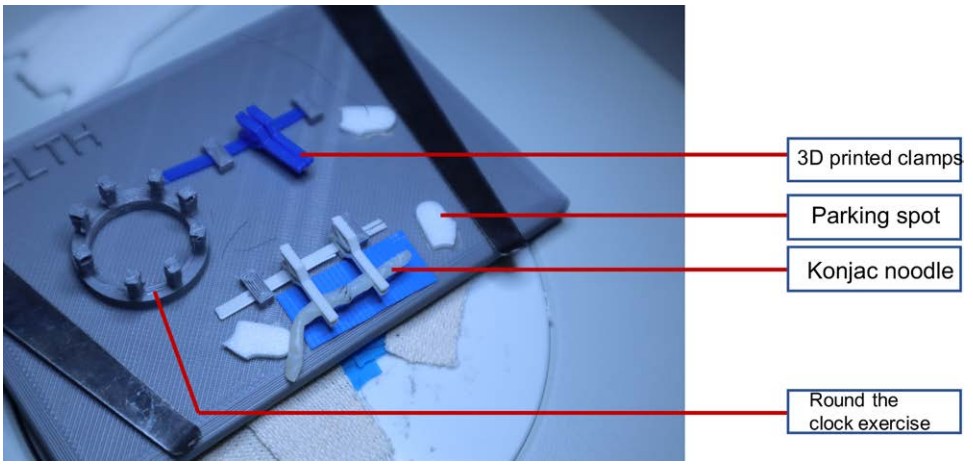


Fig. 1. The 3D printed simulator with the use of Konjac noodle. The annotations show the different features of the device, including the "round the clock" platform, the parking spot (for secure handling of the needle in between anastomosis) and the 3D printed clamps.[9]

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(S&T, US). The development of the microsurgical training model has been described elsewhere.[8] Participants' confidence performing a microvascular anastomosis and previous microsurgical experience were determined before enrollment in the course. All participants were exposed to the same training opportunities outside the simulation module.

Study Procedure

All study participants were given a standardized in-person demonstration of training platform set up. Participants were then asked to complete a front wall anastomosis using the microsurgical training model. Blinded assessment of baseline technical skill was performed by two expert microsurgeons at our unit using the University of Western Ontario Microsurgical Skills Assessment (UWOMSA) instrument. (**See appendix, Supplemental Digital Content 1,** which displays breakdown of the UWOMSA score. **http://links.lww.com/PRSGO/C470**.)[11] The UWOMSA is a validated assessment instrument that is composed of a task-specific and global rating scale that scores participants on a five-point Likert scale (ranging from 1 to 5, with higher scores indicating better performance). After assessment of baseline skills, participants were then enrolled in the microsurgical training course.

A stepwise and progressive microsurgical training curriculum was developed and credited by the British Association of Plastic, Reconstructive and Aesthetic Surgeons as well as the Plastic Surgery Trainees Association. The curriculum is composed of four levels of technical difficulty ranging from simulated nerve coaptation to a microvascular anastomosis performed at depth with access limited by a 3D printed rib model (Figs. 2 and 3; Table 1).

Expert microsurgeons from our unit were filmed performing each of the microsurgical tasks within the curriculum using the training model. These training videos were then circulated to participants and were used as a reference standard for each task level in the curriculum. (**See Video [online],** which displays the front wall anastomosis using Konjac Noodle on the 3D printed platform.)

Training was conducted over a 1-month study period with a total training time of 15 hours. Progression through training levels was self-directed, and participants were asked to record themselves completing each task during the training program. These recordings were viewed by two independent expert microsurgeons (senior authors), and anonymized feedback was provided to study participants during the training program. At the end of the study period, participants were asked to complete a front wall anastomosis using the microsurgical training model. Technical skill was then blindly assessed by two independent expert microsurgeons using a task-specific and global rating score. Participant confidence performing a microvascular anastomosis was assessed before and after completion of the training program using an online questionnaire.

Task	Time required
Pre-course questionnaire	online 5 mins
Presentation of how to use the equipment in the microsurgical lab	face to face 30 mins
Initial skills assessment, performing simple microvascular anastomosis front wall first with the equipment	30 mins
Teaching on basic microsurgical skills and techniques	30 mins online
Simulation training on the 3D printed platform Level 1: **nerve coaptation**	2 hours
Level 2: **front wall simple anastomosis**	3 hours
Level 3: **back wall simple anastomosis**	3 hours
Level 4: **either technique of anastomosis with the use of rib simulator limited access and increased depth**	5 hours
Post course questionnaire	online 5 mins
Final assessment on performing simple microvascular anastomosis front wall first with the equipment and personalized feedback by tutors	30 mins
Total hours	**15 hours**

Fig. 2. Breakdown of all activities included in the microsurgical curriculum, including hours required on each task.

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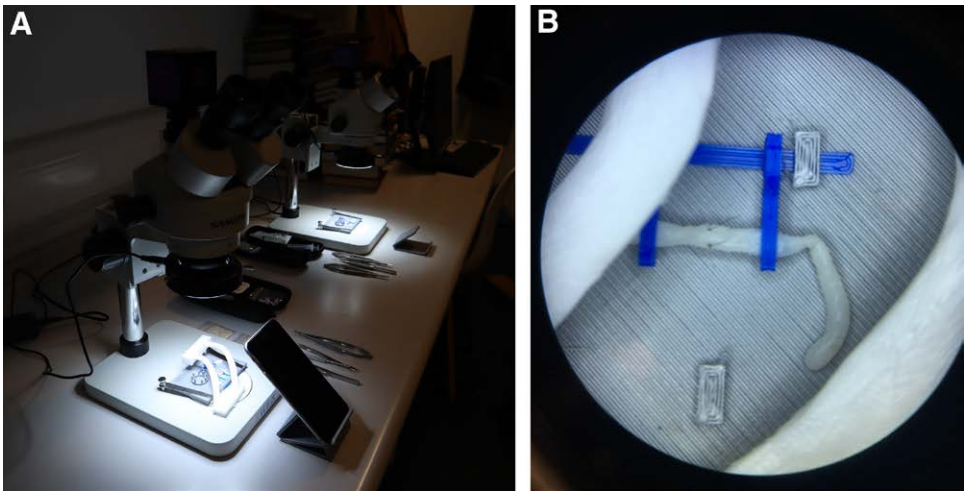


Fig. 3. The simulator applied on table microscope. A, This view shows the use of the rib simulator for advanced microsurgical training and the stand for the smartphone that the trainees used to record their performance for assessment. B, Closeup view of the Konjac noodle and the simulator under microscope magnification.

Table 1. Progressive Microsurgical Training Curriculum with Increasing Levels of Technical Difficulty

Level 1	Nerve coaptation
Level 2	Front wall simple anastomosis
Level 3	Back wall simple anastomosis
Level 4	Front and back wall anastomosis performed at depth

Data Analysis

Descriptive statistics are reported as median ± IQR (interquartile range) where applicable. Inter-rater reliability between assessors was evaluated between intraclass correlation coefficients. Intraclass correlation coefficients between 0.5 and 0.75 were deemed moderate, 0.76 to 0.9 were deemed good, and intraclass correlation coefficients more than 0.9 were deemed excellent.[12] Normality of data was determined with the use of the Shapiro-Wilk test. Nonparametric pairwise comparison of pre- and postcourse assessment scores was performed with the use of the Wilcoxon signed rank test. Observed changes were considered statistically significant at P values less than 0.05. All analyses were performed in R version 4.0.5.

RESULTS

Study Participants

A total of 10 participants were recruited from our institution. All participants were plastic surgery residents in postgraduate years 1 to 6. Participants had varying levels of microsurgical experience before enrollment in the course (Table 2).

Collectively, 50% (n = 5) participants had attended a microsurgery training course before study enrollment. All participants who had previously attended a microsurgery training course had experience on both live animal models and simulation platforms using synthetic material.

Table 2. Participant Demographics and Self-reported Microsurgical Experience before Intervention

Post graduate year (PGY)	N
1	5
2	0
3	3
4	0
5	1
6	1
Number of digital nerve repairs performed as primary surgeon	
0	4
1–5	0
6–10	0
>10	6
Number of microvascular anastomoses performed as primary surgeon	
0	4
1–5	1
6–10	5
>10	0

Participant Performance

There was a significant improvement in technical skill scores following completion of the microsurgical training program in both vessel preparation from a pretraining median of 3 (IQR 2–4) versus a posttraining of 4 (IQR 3–5) with $P = 0.0035$ and microsuturing domains with a pretraining median of 3 (IQR 2–4) versus a posttraining of 4 (IQR 3–5) with $P = 0.0047$. There was a significant improvement in global rating score following completion of the microsurgical training program (3 ± 1 versus 5 ± 1, $P = 0.0045$; Table 3).

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Table 3. Technical Skill and Global Rating Scores Pre- and Postintervention

	Preintervention	Postintervention	
	Median ± IQR	Median ± IQR	*P*
Preparation of vessels	3 ± 1	4 ± 1	0.0035*
Microsuturing	3 ± 2	4 ± 1	0.0047*
Global rating	3 ± 1	5 ± 1	0.0045*

*Statistically significant.

Table 4. Interrater Reliability

	Preintervention		Postintervention	
	ICC	95% CI	ICC	95% CI
Preparation of vessels	0.62	0.05–0.89	1	N/A
Microsuturing	0.93	0.76–0.98	0.91	0.69–0.98
Global rating	0.92	0.74–0.98	0.69	0.19–0.91

Interrater reliability testing demonstrated moderate agreement between the two raters in preintervention vessel preparation and postintervention global rating. Strong agreement between raters was demonstrated for all other pre- and postintervention assessment domains (Table 4).

Participant Confidence

Participants were asked how confident they felt performing a simulated microvascular anastomosis before and after completion of the microsurgery training program. Preintervention, 60% of participants (n = 6) indicated they were "somewhat not confident," and the remaining 40% of participants (n = 4) indicated they were "neither unconfident nor confident" in performing a microvascular anastomosis. Postintervention, 60% of participants (n = 6) indicated they were "neither unconfident nor confident," 20% of participants (n = 2) were "somewhat confident" and 20% (n = 2) were extremely confident in performing a microvascular anastomosis. Participants were also asked whether they felt anxious at all during the microsurgery training program; 40% of participants (n = 4) were not anxious at all and 60% of participants (n = 6) were occasionally anxious.

DISCUSSION

The Konjac noodle model was first described in 2014.[13] Prunieres et al conducted a prospective cohort study which compared patency, time to completion anastomosis, number of stitches and anastomotic tightness in a rat femoral artery and Konjac noodle model.[14,15] Study participants collectively performed 60 rat femoral and 62 Konjac noodle anastomoses. The authors conclude that Konjac noodle model represents an adjunct to traditional microsurgical training techniques. To our knowledge, this is the first study that demonstrates significant improvement in microsurgical skill acquisition using the Konjac noodle model.

Our data demonstrate that a structured and progressive microsurgical training curriculum using the Konjac noodle model and a novel 3D printed platform leads to measurable and significant improvements in microsurgical skill. A recent systematic review identified a number of microsurgical skill assessment tools, including motion tracking devices, objective structured assessment of technical skill tools, global rating scales, and self-reported assessment tools.[16] In the present study, we selected the anastomosis module of the UWOMSA tool for assessment of microsurgical skill. It is the only microsurgical assessment tool with evidence of content, construct and criterion validity with acceptable inter- and intrarater reliability.[11,17] In the development and validation study the UWOMSA, study participants were filmed performing a microvascular anastomosis using a chicken leg model. Reznick's global rating scale was used as a gold standard measure to determine criterion validity and construct validity was assessed through comparison with training level, time to task completion (microsurgical knot tying) and prior microsurgical experience.[16] The inter-rater reliability of UWOMSA scores between assessors in our study (as measured by intraclass correlation coefficient) is comparable with previous inter-rater reliability estimates.[11]

In the original UWOMSA development and validation study, Temple et al performed blinded video assessment of microsurgical skill using a microscope mounted camera. Our platform utilized participant mobile phones mounted to a 3D printed jig as a recording device (Figure 3a). Participant smartphones had between 3-5x magnification and produced high quality videos for assessment. Utilization of participant's own devices reduced cost and enabled participants to perform training exercises at their own discretion. Mobile-based video assessment offers several advantages compared with conventional in-person competency-based assessment. Blinded video analysis reduces the logistical burden of in-person assessment and risk of recall bias.

Task-specific feedback can be provided directly to residents as they progress through the microsurgical learning curve. Objective measures, such as the UWOMSA, provide a quantitative benchmark that residents and programs can use to measure and optimize performance. Beyond institutional assessment, mobile-based video assessment offers scope for crowd-sourced assessment of technical skill to reduce burden placed on program directors and expert surgeons. A study by Chen et al demonstrated that surgery-naive assessors from the general population can rapidly assess robotic and laparoscopic surgery skill levels using a validated assessment tool and give equivalent assessment scores to expert surgeon assessors using the same tool.[18]

The limitations of our study must be considered when interpreting these results. All participants were recruited from our institution, which may limit the ability to extrapolate the study findings. The study sample size is comparable to similar studies investigating the effect of simulation in skill acquisition in plastic surgery residents but is nonetheless small and is a notable study limitation.[14,15] The study is further limited by heterogeneity in preintervention microsurgical skill and experience. Composite analysis with a limited sample size may mask intervention effect across the microsurgical learning curve.

Despite the limitations, this microsurgical training platform permits the development of task-specific microsurgical skills (namely vessel preparation, front and backwall anastomosis). Admittedly, our platform does

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not permit the development of microsurgical dissection skills, nor does it enable users to assess flow following completion of microsurgical anastomoses as is offered with live animal models, but it does allow significantly reduced platform cost, portability, and reproducibility while avoiding the ethical and maintenance costs of live animal models. Though seemingly simple in construct, our model is versatile and can offer a range of simulated clinical cases, which require various levels of microsurgical skill. Smaller diameter noodles can be used to simulate small caliber vessels, pedicle length can be altered, and simulated ribs can be included to replicate suturing at depth (Fig. 3B).

Future prospective cohort studies with plastic surgery residents with varying levels of microsurgical experience should be conducted. Mobile-based video assessment using the UWOMSA before and after completion of a microsurgical training curriculum will enable determination of the impact of microsurgical simulation using benchtop models across the microsurgery learning curve. This will enable programs to tailor microsurgical training to individual skill level and identify residents who are suitably skilled to perform clinical microsurgery. Assessment scores from expert microsurgeons can then be compared with crowd-based assessment scores; if no significant difference is found, the feasibility of using crowd-sourced assessment of microsurgical skill should be determined. Assessment scores generated through either expert or crowd-sourced methods could be used to develop image analysis algorithms that provide immediate performance metrics to microsurgical trainees.

CONCLUSIONS

We have demonstrated that a structured progressive microsurgical training program leads to measurable and significant improvements in microsurgical skill using the Konjac noodle model and a novel 3D printed platform. We have demonstrated the feasibility of self-initiated video-based assessment of microsurgical skills. Future work should determine the impact of the Konjac noodle model across the microsurgical learning curve and investigate the feasibility of developing machine learning algorithms for video-based assessment to reduce the time constraints associated with the traditional apprenticeship model of surgical training.

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DISCLOSURES

Theodora Papavasiliou is a co-founder of Stelth, a company that specializes in 3D printing. All the other authors have no financial interest to declare in relation to the content of this article.

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