The Flower Petal Training System in Microsurgery

Validation of a Training Model Using a Randomized Controlled Trial

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Introduction: Despite hundreds of training models for microsurgery being available in the literature, very few of them are scientifically validated. We chose to validate our low-fidelity training model on flower petals by comparing it head-to-head with a moderate fidelity training model, the anastomosis on chicken leg femoral artery.

Materials and methods: A total of 16 participants of different levels of expertise were randomized into 2 groups, 1 training on flower petals and 1 on chicken leg femoral arteries. The groups were evaluated on performing a rat femoral artery anastomosis using the validated Stanford Microsurgical Assessment (SMaRT) Scale. The Mann-Whitney *U* test was used to check for statistically significant differences between the groups. The flower petal sutures were also evaluated and Pearson correlation was used to check for associations between better petal anastomosis scores and better final SMaRT results.

Results: After 6 weeks of flower petal training, microsurgical trainees had significantly better overall SMaRT scores than trainees using chicken leg training, better fine tissue feeling, and better scores in knot tying. The anastomosis times for the rat femoral arteries did not differ between the 2 groups. Good scores for flower petals strongly correlated with a better SMaRT score for the anastomosis. The number of rats used in training reduced after the implementation of this model in continuous training.

Conclusions: The flower petal technique, despite being a low-fidelity model, shows superiority in developing fine tissue feeling and improved knot tying in microsurgery beginners and intermediate level practitioners adding this training model to their program. Further research needs to establish if the improvements also apply to already seasoned microsurgeons and whether the petal score has predictive value for future clinical application.

Key Words: microsurgery, microsurgical training, validated models, microvascular anastomosis, teaching paradigm

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Over the past 10 years, discussion about the proper way to train future microsurgeons has been the focus of numerous studies.[1–5] Important conclusions of this work have centered on the importance of validating new training models while ensuring the maximum benefit in the shortest time and reduce reliance on laboratory animals.[4,6,7]

Furthermore, the increasing importance of the 3 Rs for training (replacement, reduction, and refining) requires microsurgical instructors worldwide to find new ways of teaching the haptics of microsurgery while reducing the need to use living animals used solely for training purposes with high-fidelity models, such as the rat femoral artery or the rat aorta. Such new models should be able to mimic the subtle sensory input qualifications for touch and feel, which are involved in microsurgical practice.

A recent review showed that to date only 9 validated models are available in the literature. The criterion standard of microsurgical training, the rat femoral artery anastomosis, is validated as a training model in only one study.[8]

The *Floreasca* microsurgical laboratory is one of the scarce few of its kind, training students and residents in experimental microsurgery and conducting research in composite tissue transplant, under the supervision of one of the senior authors (D.G.Z.). Within this program, young students and residents interested in joining the transplant program are trained by senior researchers and microsurgeons in the laboratory to proficiently perform microvascular anastomoses. The training models used are, according to their resemblance of actual intraoperative vessels, low-fidelity (latex, leaves, petals), moderate-fidelity (chicken leg femoral vessels), and high-fidelity models (living rats).

Since 2011, the flower petal model was introduced in the routine basic training program of the Floreasca hospital, under the supervision of the first author (V.V.). Despite concerns that petals are very fragile and not a suitable model to simulate vessel walls, empirical data and experience in teaching young trainees the finesse required for microsurgery suggested that this model can be very helpful in a training program. After all, an article showing the learning curve in venous anastomosis shows that even in the best hands and a controlled laboratory environment the patency of these anastomoses does not reach 100%.[9] Because this is most likely an issue of finesse and technique that needs constant improvement, we hypothesized that the flower petal model might teach the proper psychomotor skills.

Thus, we conducted a randomized controlled trial to both test this hypothesis and validate the flower petal model.

MATERIALS AND METHODS

The Carol Davila University's Animal Ethics' Committee approved this experiment as part of the ongoing educational program in microsurgery and composite tissue transplantation research program. All participants were asked for consent, and the data were recorded anonymously.

Over the course of 2 years, all new trainees enrolled in the Floreasca experimental microsurgery laboratory were randomized into 2 groups. Both groups followed the same rigorous training regimen in our laboratory (see hereafter) to eventually perform composite tissue transplants in rats. The control group trained 3 hours a week extra on chicken leg femoral anastomosis, and the intervention group trained 3 hours extra a week using flower petals.

The trainees had all completed a microsurgical workshop and were selected to train in experimental microsurgery. Sixteen participants were randomized. Two of these were experienced microsurgeons, 2 were residents with some experience in microsurgery, 2 residents without experience in microsurgery, and 10 were students with research interest in experimental microsurgery. The distribution of experienced and inexperienced participants was equal between the 2 groups.

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The workshop was a 3-day, 36-hour course that took practitioners without experience through a stepwise approach from the basic models and chicken leg anastomosis in the first day to the rat aorta and sciatic nerve the second day and the rat femoral artery and carotid in the last day. Participants usually could perform a rat femoral anastomosis (without the dissection) in less than 1 hour.

Upon finishing the microsurgery workshop and being selected for the experimental microsurgery program, each participant was randomized once consent to participate was obtained. The randomization was done using a computer program. Each participant was then required to perform a femoral artery anastomosis in a rat to obtain baseline measurements of proficiency using the Stanford Microsurgical Assessment (SMaRT) Scale.[10] Even though this scale was not specifically designed for the rat femoral artery model, we felt that the validation and the areas tested would provide sufficient insight and would be able to adequately summarize the effect of adding the flower petal model in microsurgical training. The time needed to perform the anastomosis (without the dissection part) as well as the SMaRT scores and the level of experience were recorded in a spreadsheet. The subsequent training and evolution were supervised by the first author (V.V.) and the senior author (D.G.Z.). Upon completion of the program, all participants were again evaluated using the SMaRT scale. All assessments were performed by the same author (V.V.).

The patency of the anastomosis was also evaluated and recorded at 30 minutes using the milking test. Only strong pulsations and immediate filling were considered patent. Slower filling was considered not patent.

Training Regimen

The 6-week training program consisted of a gradual buildup of microsurgical techniques. The training was given by the more senior researchers in the laboratory. The trainees would be required to attend 5 training days of 4 to 5 hours a week, the *basic* first 3 weeks consisting of a progression from rat aorta end-to-end anastomosis, rat carotid, and femoral artery end-to-end, moving on to the femoral vein and inferior vena cava. The following 3 weeks were dedicated to more *advanced* techniques, like interpositional grafting on various vessels, bypasses, various organ harvesting from the abdomen, and culminating with the renal heterotopic cervical transplantation with a stoma.

During their training, the control group used chicken leg femoral arteries 9 hours a week to brush up on details of technique regarding microvascular anastomoses, whereas the intervention group did 6 hours of flower petal sutures and 3 hours of chicken leg parallel to the advanced techniques on rats.

For training with flower petals we used, in descending order of difficulty, *Tanacetum cinerariifolium*, *Rosa damascena*, and *Chrysantemum maximum*. We observed a different sturdiness and chance of rupture in the different types of petals.

Only the group training with flower petals was also assessed to document progression of their technique with this model using a scale of 1 to 9. This was made up of 3 domains, knot tying, symmetry, and control (Table 1). The sum of these 3 domains resulted in the final overall score for the flower petal technique. At the end of every training week, the participants from the intervention group were evaluated by the first author (V.V.). The first and last scores were used for analysis. Questionnaires were handed out to the participants with questions regarding the usefulness of the flower petal training and whether they would use it again in the future.

Statistical Analysis

The distribution of data were tested for normality using the Kolmogorov-Smirnov test, and this showed no normal distribution, except for the anastomosis times. Therefore, we chose to describe the data using medians and interquartile ranges (IQRs) and perform the analysis using nonparametric tests. The Wilcoxon signed rank test was used to test the difference in medians before and after the training period, and the Mann-Whitney *U* test was used to test the medians between the control and the intervention groups. A P value of <0.03 was considered significant, correcting for multiple testing.

RESULTS

The median anastomosis time for all participants before the 6 weeks training was 44 minutes (IQR, 30–47 minutes). After the training for all participants, the median anastomosis time was 35 minutes (IQR, 25.5–38.8 minutes; $P = 0.03$).

For the control group, the median anastomosis time before the training was 41.5 minutes (IQR, 28.8–47 minutes), and for the intervention group, 46 minutes (IQR, 30.2–52 minutes). The median time for the control group after the training was 36 minutes (IQR, 25.2–38.8 minutes), and for the intervention group after the training, 34 minutes (IQR, 25.5–36.5 minutes). One-way analysis of variance showed no difference between the control and intervention groups both before and after the training ($P = 0.89$ before the training and $P = 0.69$ after the training).

The median SMaRT scores before the training were not statistically different between the 2 groups (Mann-Whitney *U* test). For both groups, the SMaRT total scores after the training were significantly higher than before (Wilcoxon signed rank test, $P < 0.0001$). When comparing the control and intervention groups among all domains (Table 2), the SMaRT overall score after training showed a higher trend in the intervention group but barely reached significance (Mann-Whitney *U*, $P = 0.05$). The score for tissue handling ($P = 0.02$) and for knot tying ($P = 0.01$) was significantly higher in the intervention group (flower petal).

The anastomosis was patent in 7 of 8 rats in the intervention group and in 4 of 8 in the control group. The difference was not significant using the McNemar test ($P = 0.54$).

The median score for the petal sutures was 3 before the training (IQR, 3–4) and 6 after the training weeks (IQR, 5.25–7). All participants evolved in this respect, as the scores were higher after the training (Wilcoxon signed rank test, $P < 0.0001$). When testing for correlations using Spearman rank correlation coefficient, the last petal score correlated most strongly with the level of experience (Spearman coefficient, 0.89; $P = 0.003$), SMaRT tissue handling (Spearman coefficient, 0.87;

TABLE 1. The Scoring System for the Flower Petal Sutures

Domain	Score		
Knot tying	1	2	3
	Poorly ties knots, too loose or too tight		Consistently well-tied knots with equal tension
Symmetry	1	2	3
	Asymmetrical sutures with unequal bite sizes		Equal bite sizes and suture spacing
Control	1	2	3
	Large holes in the flower petal with frequent cuts		Minimal damage to the flower petal

TABLE 2. Baseline Results and Outcomes Before and After the Training for the Control and the Intervention Groups

Score	Control Group, Chicken Leg Femoral Anastomosis, Median (IQR) (n = 8)	Intervention Group, Flower Petal Suture, Median (IQR) (n = 8)	*P*
Before training program—baseline			
Anastomosis time	41.5 (28.5–47)	46 (30.5–52)	0.89
SMaRT instrument handling	3 (2–4)	3 (2–4)	0.70
SMaRT tissue handling	2 (2–2.5)	2 (1–3)	0.80
SMaRT efficiency	2 (2–2.5)	2 (1.5–3)	0.58
SMaRT suture handling	2 (1–3)	2 (1–3)	1.0
SMaRT suturing technique	2 (1–3)	2 (1.5–3)	0.80
SMaRT knot quality	2 (1–3)	2 (1–3)	0.88
SMaRT final product	2 (1–3)	1.5 (1–3)	0.80
SMaRT operation flow	2 (1.5–3.5)	2 (1–3.5)	0.80
SMaRT overall performance	2 (1.5–3.5)	2 (1.5–4)	1.0
SMaRT total score	19 (14.5–28)	17.5 (12–27.5)	0.80
After the training—outcome			
Anastomosis time, mean (SD)	36 (25.5–39)	34 (25.5–39)	0.69
SMaRT instrument handling, median (IQR)	3 (3–4)	3 (3–4)	1.0
SMaRT tissue handling	3 (2.5–4)	4 (4–5)	**0.02**
SMaRT efficiency	2.5 (2–4)	3 (2.5–4)	0.64
SMaRT suture handling	2.5 (2–3)	3 (2.5–4)	0.44
SMaRT suturing technique	3 (2–3)	3 (3–3)	0.44
SMaRT knot quality	2 (2–3)	4 (4–5)	**0.01**
SMaRT final product	2.5 (2–3)	3 (3–4)	0.12
SMaRT operation flow	2.5 (2–4)	2.5 (2–4)	1.0
SMaRT overall performance	3 (3–3.5)	3.5 (3–4)	0.50
SMaRT total score	23.5 (21.5–31.5)	29 (28–34.5)	0.05

Bold data indicates statistically significant.

$P = 0.005$), the time required to perform the anastomosis (Spearman coefficient, −0.89; $P = 0.003$), and the level of experience in microsurgery of the participant (Spearman coefficient, 0.89; $P = 0.003$).

For the questionnaires handed out after the training, 7 from the 8 participants responded that they found the training "very useful" and that they would certainly use the technique in their future training.

DISCUSSION

In a randomized trial embedded in a training setting, we assessed whether the introduction of the flower petal suture training would have a positive impact on the performance of microvascular anastomosis evaluated using the validated SMaRT scale. The intervention group (flower petal model) performed better than the control group (chicken leg femoral artery) both in the domains of tissue handling and knot tying, as well as the overall score.

The flower petal model is a valid and inexpensive model for microsurgical training. However, a few caveats need to be considered when introducing this model. Different flowers have a different degree of friability. Petals contain cells, which are surrounded by walls that provide structural support and protection to the cell itself. In addition, the cell wall tensile strength restrains the cell's turgor pressure, caused by

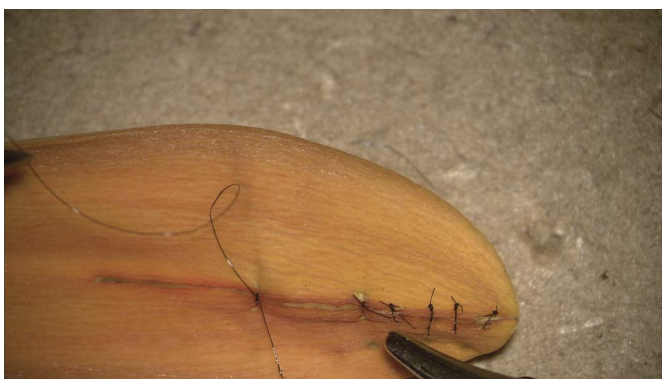

FIGURE 1. Sutured petal exhibiting many mistakes, among which are improper alignment of edges, asymmetrical knots, large holes, and unequal tension (Carl Zeiss Opmi 900 operating microscope, 14× magnification).

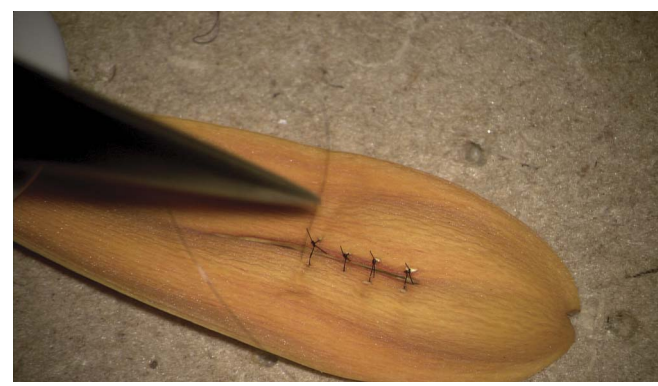

FIGURE 2. Sutured petal showing small holes and proper alignment as well as good knot tension and symmetry (Carl Zeiss Opmi 900 operating microscope, 14× magnification).

the osmotic flow of water into the cell.[11–13] Reversely, in most plant cells, turgor pressure is required to maintain cell wall rigidity, and it is essential for plant cell growth.[14,15]

Chrysantemum spp petals are roughly 250 μm thick and contain parenchyma tissue that consists of densely packed cells with small intercellular spaces and occasionally a vascular bundle. In contrast, *Rosa* spp petals are roughly 150 to 200 μm thick and consist of an upper and lower epidermis, both roughly 15 to 20 μm thick, surrounding a layer of parenchyma cells with dispersed vascular bundles. The petal parenchyma of this species is likely to be more prone to rupture owing to the large intercellular spaces, the lower cell number, and the larger cell sizes than the parenchyma of *Chrysantemum* spp, which is likely to provide more structural strength owing to the higher density and smaller sizes of cells. If the epidermis of *Rosa* spp ruptures, the observed "bleeding" may be explained by rupturing of the large parenchyma cells.

Some results of our study were surprising and counterintuitive. Although we can understand a significant difference in tissue handling after practice with the flower petal model, we did not expect better proficiency in knot tying. However, while observing the intervention group, it was clear that to improve the skill of flower petal suturing, participants in the intervention group had to work slower and pay more attention to the quality and tension in the knots. When performing the sutures, participants in the intervention group would pay much more attention to every detail of knot tying (flatness, proper alignment, bite size, symmetry) than participants not exposed to the flower petal model (Fig. 1). This might also explain the negative correlation of the petal suture score with the anastomosis time after the training weeks (Fig. 2). The added benefit for tissue handling and knot tying comes, at least initially, at the expenses of slower anastomosis times. However, when comparing the mean anastomosis times for both groups, the difference was not statistically significant.

Although the overall score was better in the intervention group, neither the efficiency, the flow of the operation or the overall product was significantly different between the 2 groups. It is possible that our study was underpowered to detect improvement in the end product, despite better tissue handling and knot tying among trainees in the flower petal group. We speculate that, given more time than the 6 weeks we allowed and more participants, the end product would be significantly better in the intervention group. Based on these observations, we redesigned our training program to include exercises meant to improve efficiency and procedural flow.

Although it may seem that the flower petal model was designed as an entry-level training supplement, we feel that it might add in finesse and improvement even with experienced microsurgeons, which is why we use it frequently as part of the continuous training of seasoned microsurgeons as well as beginners. The former report improvement of hand-eye coordination and control of finer movements. An objective assessment of the flower petal training model with experienced microsurgeons is underway; however, we consider it an intermediate-level exercise.

After the implementation of the flower petal suture, less live rats were used in the laboratory. We evaluated their use before and after the implementation of the flower petal training model. The number of trainees did not differ significantly, but the number of rats was reduced by half. We did not take into account the rats used in microvascular courses given by the laboratory. The study protocol did not take the number of rats into account as secondary outcome, but the reduction was important enough to warrant reporting.

Although the results of the anastomoses of the trainees did not differ, the need for live animals was reduced to moments of evaluation of techniques used to refine anastomoses. In this way, the techniques on live rats were only used to confirm proper skill acquisition in nonliving models and less as the only manner of training, as was often the case for experienced microsurgeons before.

Limitations

The limitations of this study were the limited number of participants, the moderately short follow-up time between the 2 evaluation moments, and the unblinded evaluation of participants. The 6-week period was based on our previous experience and the median time required for a trainee to reach a proficient level in microvascular anastomoses with continuous training.

The unblinded evaluation of participants is a limitation, as it could induce the bias of better evaluation of the flower petal group. However, we needed a realistic evaluation of all participants to the training program from our laboratory, hence why we always perform very strict evaluations.

Our sample did not have sufficient statistical power to detect statistical significance in terms of the anastomosis patency.[16] The evaluation of the anastomosis and the anastomosis time were similar between the intervention and control groups, but the implementation of the flower petal training did translate into patent, qualitatively good anastomoses performed in under 35 minutes, which triggered us to broadly implement this technique in the laboratory training and in all our subsequent microsurgical courses.

The use of less live rats after the implementation of the flower petal model might have other explanations as well. We are now used to using a combination of flower petals and chicken leg anastomoses to form the basis of training, which needs to be consistently confirmed using live rats. In this way, the need for live animals is not absent but it is significantly decreased. The end products of those training in the laboratory after the implementation of the model have not become worse, but this has not been formally tested in a protocol for the purposes of this study. Moreover, only 4 years' worth of data is available, 2 years before and 2 years after the implementation of the model, and for just a single laboratory. An implementation of this model on a larger scale needs to be performed before clear-cut conclusions are drawn, and a cost-effectiveness analysis also needs to be used.

Further research is needed to establish the role of the flower petal training model in the maintenance of skill of already experienced microsurgeons. Currently, we use this model with a frequency of once a week for skill maintenance even for experienced residents or staff members. Given our results, face and content validity were demonstrated, as well as construct and concurrent validities for fine tissue handling and knot tying.

CONCLUSIONS

In this randomized trial, practice with a low-fidelity model (the flower petal suture) when compared with a moderate-fidelity model (the chicken leg femoral anastomosis), in combination with our usual 6-week training program, resulted in significantly better fine tissue handling and knot tying among participants with different levels of experience.

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