High Fidelity Microsurgical Simulation: The Thiel Model and Evaluation Instrument

La simulation microchirurgicale haute-fidélité : le modèle et instrument d'évaluation Thiel

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Abstract

Background: The Thiel embalment method has recently been used in a number of medical simulation fields. The authors investigate the use of Thiel vessels as a high fidelity model for microvascular simulation and propose a new checklist-based evaluation instrument for microsurgical training. **Methods:** Thirteen residents and 2 attending microsurgeons performed video recorded microvascular anastomoses on Thiel embalmed arteries that were evaluated using a new evaluation instrument (Microvascular Evaluation Scale) by 4 fellowship trained microsurgeons. The internal validity was assessed using the Cronbach coefficient. The external validity was verified using regression models. **Results:** The reliability assessment revealed an excellent intra-class correlation of 0.89. When comparing scores obtained by participants from different levels of training, attending surgeons and senior residents (Post Graduate Year [PGY] 4-5) scored significantly better than junior residents (PGY 1-3). The difference between senior residents and attending surgeons was not significant. When considering microsurgical experience, the differences were significant between the advanced group and the minimal and moderate experience groups. The differences between minimal and moderate experience groups were not significant. Based on the data obtained, a score of 8 would translate into a level of microsurgical competence appropriate for clinical microsurgery. **Conclusions:** Thiel cadaveric vessels are a high fidelity model for microsurgical simulation. Excellent internal and external validity measures were obtained using the Microvascular Evaluation Scale (MVES).

Résumé

Historique : La méthode d'embaumement Thiel a récemment été utilisée dans divers domaines de simulation médicale. Les auteurs explorent l'utilisation des vaisseaux Thiel comme modèle haute-fidélité pour la simulation microvasculaire et proposent un nouvel instrument d'évaluation de formation à la microchirurgie reposant sur une liste de vérification. **Méthodologie :** Treize résidents et deux microchirurgiens traitants ont effectué des anastomoses microvasculaires sur des artères embaumées Thiel. Quatre microchirurgiens surspécialisés en ont évalué l'enregistrement à l'aide d'un nouvel instrument (échelle de simulation microchirurgicale en dix étapes). Ils ont évalué la validité interne au moyen du coefficient de Cronbach et vérifié la validité externe à l'aide de modèles de régression. **Résultats :** L'évaluation de fiabilité a révélé une excellente corrélation intraclasse de 0,89. Lorsqu'on compare les scores obtenus par des participants de divers niveaux de formation, les chirurgiens et les résidents seniors (de quatrième ou cinquième année) ont obtenu des résultats significativement supérieurs à ceux des résidents juniors (de

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première à troisième année). La différence entre les résidents seniors et les chirurgiens traitants n'était pas significative. Les différences d'expérience microchirurgicale étaient significatives entre le groupe avancé et les groupes ayant une expérience minimale ou modérée. D'après les données obtenues, un score de 8 désignerait un niveau de compétence microchirurgicale acceptable pour la microchirurgie clinique. **Conclusions :** Les vaisseaux cadavériques Thiel sont un modèle haute-fidélité de simulation microchirurgicale. D'excellentes mesures de validité interne et externe ont été obtenues au moyen de l'échelle de simulation microchirurgicale en dix étapes.

Keywords

simulation, microsurgery, Thiel, microvascular

Introduction

Microsurgery is a discipline unlike other surgical specialties. The hand–eye coordination is mediated by a microscope, which betrays even the most benign shaking and reduces the depth of field perception significantly. Harmonious surgical gestures take some additional training that macroscopic surgical procedures do not require. As such, there is a steep learning curve until trainees, who may well have mastered macroscopic surgical procedures, are able to safely perform an effective microvascular anastomosis or nerve coaptation. We emphasize “safely,” as this is in our opinion the rate limiting step for a surgeon to allow a trainee to perform an anastomosis in a clinical setting. It is therefore important for trainees to gain experience in a simulation model before performing microvascular anastomoses in the clinical setting. Whenever possible, the learning curve should be mastered in the lab.

The fidelity of a simulation model is a measure of how realistic the model is. While fidelity is a spectrum, many authors refer to low and high-fidelity models. Live animal models, such as the rat femoral vessels, are a high fidelity model for training. There are a number of drawbacks which, while not precluding the use of these models, at the very least discourage their extensive utilization. Live animals are expensive, require special facilities and staffing, have a steep learning curve. However, the foremost arguments against their use for live models in microsurgical training are of an ethical nature. Ethical concerns have prompted the “three R” principles of refinement, reduction and replacement.¹ In the case of microsurgical training, the replacement has included ex vivo models such as chicken wings^{2,3} or legs,⁴ formalin-fixed cadaveric vessels,⁵ as well as silastic models.⁶ A number of these models were reviewed by Lannon et al, the authors characterizing the strengths and weaknesses of the described models.⁷ Douglas and Mackay compared the rat aorta, practice rat and chicken wing vessels and found the chicken wing model to most closely resemble human vessels.⁸

More recently, the Thiel cadaveric model has also been described for flap dissection as well as microvascular exercises.⁹ The Thiel method of embalming uses a complex solution containing boric acid, ethyleneglycol, and a number of salts to denature proteins and preserve tissue. Unlike formalin embalment, tissues maintain the texture, elasticity, volume, and color of fresh cadavers. Unlike fresh cadavers, Thiel cadavers can be used for extended periods of time. We have previously published

our experience with the use of Thiel embalmed cadaveric vessels as a model for microsurgical research.^{10,11} These vessels are a high fidelity model for microvascular simulation since they maintain good handling properties for extended periods of time, maintain the vascular architecture with an intima, media, and adventitia, have a caliber that most surgeons may be performing microvascular repairs/anastomoses on, and at the same time they are in keeping with the “three R” ethical principles.

To our knowledge, the only validated method for assessing microsurgical skills was published by Temple and Ross from the University of Western Ontario in Canada.⁴ The “University of Western Ontario Microsurgery Skills Acquisition/Assessment” instrument (UWOMSA), inspired by the “objective structured assessment of technical skills (OSATS)” checklist,^{12,13} has 2 modules: a knot tying module and an anastomosis module. Each module consists of three subsections, graded on a scale from 1 to 5. Although Temple and Ross contributed a valuable, validated model and evaluation instrument, it has some shortcomings. For example, one can arrive to a score of 3 on any of the subsections by a number of permutations of the gestures involved. This limits the usefulness as a feedback instrument for the trainee, as a total score of 10 could mean a whole array of different technical errors combined. Furthermore, it is not clear what score would correlate with a skill level adequate to progression of the trainee to either the animal model or the clinical setting.

The first objective of this study is to test the utility of the Thiel embalmed cadaveric vessels as a simulation model in microsurgery. The second objective was to design and validate a new evaluation instrument, geared toward microsurgery. Finally, we aim to determine what score a trainee need to obtain with the evaluation instrument in order to be considered “safe” to provide microsurgical assistance in the operating room.

Methods

Thiel Vessel Specimens

Radial and ulnar arteries were harvested together with the venae comitantes from Thiel embalmed cadavers and stored in Thiel embalming solution at 4°C. One length of vessel could be used for multiple microvascular anastomoses. The average diameter of the vessels was 3.5 mm. For the purpose of this module, a length of 7 cm of vessel was placed in a previously modified Petri dish with vascular ports on both ends as shown

Figure 1. Set-up used for microvascular training.

Table 1. Participant Information.

Participant	PGY	Age	Sex	Specialty	Experience
1	5	38	M	Plastic surgery	>1 and ≤10
2	2	25	M	ENT	≤1
3	3	29	M	Plastic surgery	>1 and ≤10
4	3	26	M	Plastic surgery	>1 and ≤10
5	2	29	F	ENT	≤1
6	2	39	M	Neurosurgery	≤1
7	2	28	F	Plastic surgery	≤1
8	4	28	M	Plastic surgery	>1 and ≤10
9	Attending	47	M	Plastic surgery	>10
10	3	28	F	Plastic surgery	>1 and ≤10
11	Attending	42	M	Plastic surgery	>10
12	5	39	M	Plastic surgery	>10
13	5	34	F	Plastic surgery	>10
14	1	23	F	Plastic surgery	≤1
15	3	25	F	Plastic surgery	>1 and ≤10

a PGY 1-3 were further grouped as junior residents, PGY 4-5 senior residents.

in Figure 1. The vessel was ligated to the vascular connectors with silk suture in order to allow subsequent irrigation. For each participant, a 2 cm segment of vessel was dissected free of the venae comitantes. The vessel was then transected sharply. The trainees had to place the approximator clamps, background and perform the anastomosis. Once the anastomosis was performed, saline was instilled in the vessel to evaluate for leaks and patency. Up to 5 anastomoses could be done on the same 5 cm segment of artery. In between uses, the vessel could be placed in Thiel solution at 4°C for storage.

Study Design

An email inviting the residents and attending microsurgeons from 2 plastic surgery training program, as well as residents from one ENT and one neurosurgery program was sent out. Participation of residents from all levels of training was encouraged. Fifteen participants performed the simulation

Table 2. Microvascular Evaluation Scale.

	0	1
Adventisectomy		
Dilatation		
Perpendicular needle placement/full thickness bite		
Visualization of back wall		
Bite width and spacing between sutures		
Favorable knot placement (everted, square)		
Gentle manipulation of tissues; instrument stabilization		
Coordination of instruments, vessel, and suture		
Takes needle out on a curve		
Uses fulcrum while pulling suture		
Score:		

module, including 10 plastic surgery residents, 2 ENT residents, 1 neurosurgery resident, and 2 attending microsurgeons. Table 1 shows participant information such as program, training level (PGY level), and self-declared microsurgical experience of the participants. Data on sex and age were also collected. The experience was grouped into 3 clusters: minimal (≤1 completed anastomosis), moderate (>1 but ≤10 anastomoses), and advanced (>10 anastomoses). Given the small number of participants (n = 15), we could not evaluate differences between individual PGY levels since some of these groups only had one participant. Instead, the participants were clustered into 3 groups: junior resident (PGY 1-3), senior resident (PGY 4-5), and attending surgeons.

The participants were assigned a random participation code for the purpose of blinding the evaluation process. The demographic information of the participants, identified by the participation codes were placed individually in sealed envelopes. Data collection was done one participant at a time. The subjects were shown first a teaching video of microvascular anastomosis and the different technical elements explained. This was performed regardless of the level of training of the subject, in order to ensure that they would perform anastomoses in a similar manner, facilitating consistent grading. Participants were also allowed to get accustomed to the instrument and the microscope, after which they each performed one anastomosis which was video recorded. The videos were only identified with the 5 number randomly generated code. Four fellowship-trained microsurgeons performed a blinded evaluation of the recordings and graded them based on the scale described in Table 2. The sealed envelopes with the identifiable information of the participants were only opened upon completion of the evaluation and the data were compiled.

Evaluation Scale

The Microvascular Evaluation Scale was developed by a panel of 4 fellowship-trained microsurgeons, based on the literature and their own experience teaching microsurgery. Ten microsurgical gestures comprise the scale, with each gesture being scored either as 0 or 1, depending if it was performed inadequately or adequately. The scale range is from 0 to 10 and is shown in Table 2.

Figure 2. Level of training: group 1 represents the junior residents (PGY 1-3), group 2 the senior residents (PGY 4-5), and group 3 are attending surgeons.

Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics version 22 and SAS 9.3 (Cary, North Carolina).

The internal validity of the instrument was assessed using the Cronbach coefficient.

To assess the external validity of the instrument, univariate and multivariate analyses were performed. We used multivariate linear mixed-effects models taking into account correlations between subjects nested in microsurgeons. This approach was favored over multivariate approaches based on ordinary least square regression, since it is more flexible for repeated measure or clustered data.

Results

Microvascular anastomosis videos from 15 subjects were evaluated by 4 fellowship-trained microsurgeons, for a total of 60 observations. Each blinded evaluator scored all the trainees using the microvascular simulation scale.

Reliability Assessment

Using the 60 observations from the 4 evaluators, we determined the Inter-rater reliability, revealing an “excellent” intra-class correlation of 0.89 (0.75, 0.96).

Regression Models

Using univariate analysis, the correlation coefficient between score and level of training was 0.36 ($P < .001$) and the correlation between score and microsurgical experience was 0.79 ($P < .001$). Multivariable linear mixed-effects models revealed statistically significant differences between the scores obtained by the attending surgeons and the junior residents ($P = .002$), and

Figure 3. Microsurgical experience: group 1 represents participants with minimal experience (≤ 1 anastomosis). Group 2 represents the moderate experience (>1 and ≤ 10 anastomoses) while group 3 is the advanced group (>10 anastomoses). Group 3 was found to perform significantly better than either group 1 and 2.

between the senior and junior residents ($P = .006$). The difference between senior residents and attending surgeons were not significant ($P = .28$). These results are represented graphically in Figure 2. When considering the microsurgical experience, the differences were significant between the advanced and minimal experience groups ($P = .017$) and between the advanced and moderate experience groups ($P = .004$). The differences between minimal and moderate experience groups were not significant ($P = .35$). These results can be appreciated graphically in Figure 3 and are summarized in Table 3.

Discussion

Wolff et al proposed the used Thiel cadaveric model for use in microvascular simulation. They presented their experience with the use of this model for the dissection of flaps, as well as microvascular training and concluded that this model is versatile in the training of microsurgical and macroscopic surgical techniques. Although they used this model in the setting of the entire cadaver being used, we harvested the radial and ulnar vessels from cadavers that were about to be cremated and stored them up to one year at 4°C with no change in vessel quality. In our opinion, the most ethical use of cadaveric specimens is not to waste any part of the donor’s body, and therefore our model maximizes the ethical use of the cadavers. The shortcoming of this model is that Thiel embalment is not yet widely used, especially in North America. It offers however the promise of eventually replacing formalin preservation in anatomy labs, which would make vascular specimens like those used in this study more widely available.

The quality and size of the vessels used are very similar to vessels in the clinical setting. The exception is that the muscular layer becomes somewhat distended and thus the overall

Table 3. Multivariable Linear Mixed Models.

Effect	β Estimate	95% Confidence Interval		P Value
Experience				
>1 and ≤ 10 vs >10	-3.5208	-6.2796	-0.7620	.0166
>1 and ≤ 10 vs ≤ 1	1.1417	-1.4463	3.7297	.3554
>10 vs ≤ 1	4.6625	1.7955	7.5295	.0040
PGY				
Attending vs junior	5.1250	2.1666	8.0834	.0027
Attending vs senior	1.6875	-1.5899	4.9649	.2839
Junior vs senior	-3.4375	-5.7117	-1.1633	.0064

Figure 4. Histologic slide showing the interface between the 2 vessel ends. The 3 layers of the vessel wall can be appreciated, as well as the internal elastic lamina.

diameter of the vessel is larger than its equivalent in vivo counterpart. The adventitia, muscularis, and intima can be clearly appreciated histologically in Figure 4. The tissues are supple and handle well, allowing for adequate knot placement and edge eversion. The patency of the anastomosis can also be verified by instilling saline into the vessel lumen. While the future may bring virtual simulation models, such as already exist in laparoscopic simulation, the Thiel model is a high fidelity model for microsurgical simulation, offering vessels similar in size and texture to those seen in the clinical setting.

However a number of microsurgical models have been proposed, Temple and Ross are the only authors who have developed and validated a model and evaluation scale for microsurgical gestures. The authors used the OSATS scale¹³ as a starting point for their own scale. The OSATS, developed by Reznick and colleagues found the “global score” to correlate better with performance of the trainees they evaluated than the “checklist score.” The global rating scale they proposed is composed of 7 dimensions, each encompassing some aspect of technical performance. Each of these dimensions is graded on a scale from 1 to 5. Reznick model was developed for general surgery, the authors describe it as a universal scale that could be adapted to any procedure. Temple and Ross adapted

this global scale model to microsurgery. While the global scale correlated better with performance than the checklist scale Reznick et al used, we believe a well-structured checklist can give valuable feedback to the trainee regarding the exact aspects of their technique that need improvement. Restricting the evaluation to the 10 most critical gestures which we feel are essential for the safe performance of the procedure allows for an easy transformation of the score in a percent. Once the 10 gestures were identified we opted for a binary grading for each. Performing a gesture well would be scored with a “1;” not performing it well will attribute “0.” This is the Microvascular Evaluation Scale.

Furthermore, we wanted this evaluation instrument to be directly useful for feedback to the trainee. Being able to visualize the success or failure on a sheet allows the trainee to identify and work on specific aspects that need improvement. This is a concept different from the OSATS used in general surgery and adapted to microsurgery by Temple and Ross at the University of Western Ontario. Those scales are constructed in three subsections, each worth 5 points for a total of 15 points. However, a number of permutations of successful and unsuccessful gestures can result in a score of three, for example. A trainee would not be able to know how that score of 3 was attributed and therefore it would be impossible to use that information for meaningful feedback.

The structured assessment of microsurgical skills (SAMS) contains 3 areas of evaluation: global rating scale (GRS), errors list, and summative rating. The GRS, containing 12 items, is further subdivided in dexterity, visuo-spatial ability, operative flow, and judgement.¹⁴ While quite complete in its assessment, the SAMS has some potential flaws as well. There are so many items to grade that it can become quite difficult for the examiner to keep track. Furthermore, some of the items are much less important than others, diluting out the key gestures. For this reason we attempted to create a simplified, 10 point simulation scale covering the gestures our panel of microsurgeons considered most critical.

The 2 measures that determine the usefulness of a test or instrument are the internal and external validity. Internal validity refers to the correlation of results between 2 different examiners or on repeated trials. Agreement in our study was determined using the intra-class correlation coefficient, similar to UWOMSA. While reliability of a test refers to the ability to generate the same results on repeated trials, intra-class correlation assesses of consistency of measurements made by different observers measuring the same quantity. The intra-class correlation coefficient can vary between -1 and 1. A coefficient of 0.61 to 0.8 was considered “good” agreement and a coefficient of 0.81 to 1.00 was considered “excellent.” The inter-rater reliability of the Microvascular Evaluation Scale was excellent, with an intra-class correlation of 0.89 (0.75, 0.96). Comparatively, the UWOMSA scale of Temple and Ross revealed an intra-class correlation coefficient of 0.79 (0.62, 0.89). The SAMS showed an intra-class coefficient of 0.78. This indicates that our scale possesses an excellent internal validity.

Indicators of external validity were the correlations between the level of training and the scores, as well as between the microsurgical experience and the scores. Using univariate analysis we obtained an intra-class correlation coefficient for level of training of 0.36 ($P < .001$). Adjusted analysis using the differences of least square means showed statistically significant differences between the attending surgeons and junior residents ($P = .002$) and between senior residents and junior residents ($P = .006$). The difference was not statistically significant between the senior residents and attending surgeons ($P = .28$). These results suggest that an adequate level of microsurgical proficiency could be represented by a score mean score of 8. While our study may be underpowered to reveal significant differences between senior residents and attending surgeons, we think that another way of interpreting this result is that our scale does not discriminate between a good microsurgeon and an expert. It looks at essential gestures that can be well performed by an experienced technician at any level of training.

Univariate analysis between microsurgical experience and scores revealed an inter-class correlation coefficient of 0.79 ($P < .001$). Furthermore, adjusted analysis using the differences of least square means revealed results that were statistically significant between the minimal experience group and the advanced group ($P = .017$), as well as between the moderate experience and the advanced group ($P = .004$). The score difference was not statistically significant between the minimal and moderate experience groups ($p = 0.355$). These results suggest that microsurgical performance becomes significantly better after performing more than 10 anastomoses.

Surgical training is shifting from a time based to a competency based model. Two measures followed in this study pertain to each of this model. The level of training based on PGY and/or attending status is a reflection of the time based model of surgical training. The microsurgical experience is more in tune with the competency based model. If we look at univariate data, we observed a better correlation coefficient between microsurgical experience and score than between level of training and score (0.79 vs 0.36). This would suggest the microsurgical experience to be a better indicator of competency than the number of years in training.

If this simulation model and the Microvascular Evaluation Scale are to be implemented in a competency based training program, it becomes important to determine a benchmark score that would be associated with passing of the anastomosis module. If we consider the level of training model, a score of 7.9 was the average score of the senior residents, which was a statistically significant jump from the average score of 4.5 of the junior residents. The senior resident score was not statistically different than the score of 9.6 of the attending surgeons. Based on this data, a score of 8 could represent a good benchmark score if we consider the level of training. Based on the self-declared microsurgical experience, participants who performed more than ten anastomoses scored on average 9.1, which was statistically significant change from those who performed less than ten anastomoses. These data could indicate a score of 9 as a good benchmark score. We propose a score of 8 as our benchmark, however other surgical educators may chose the stricter standard.

We believe that this study validates the evaluation instrument we constructed for the trainee population we studied. Furthermore, the Thiel cadaveric vessel model proved to be a valuable model for microsurgical training. Recently, the SAMS scale was used by Masud et al to verify the longitudinal acquisition of skills by trainees after a 3 months training program. The authors showed a significant improvement in scores for the study group versus the control group.¹⁵ Along the same lines, future directions in our research will include a longitudinal evaluation of the progress of our resident's scores as they use the model repeatedly. This will help determine if the model is conducive to a natural progression of microsurgical skill, and if the feedback obtained from the evaluations would prove beneficial to the trainees. We plan to develop deconstructed modules that help perfect individual gestures that the trainees do not perform well, such as pulling the needle out on a curve or using a fulcrum when pulling suture. We also plan to construct similar Thiel models and evaluation instruments for other areas of plastic surgery simulation, such as flexor tendon repair or nerve repair.

Declaration of Conflicting Interests

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