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Review

Development of a training curriculum for microsurgery

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Abstract

Recent changes in healthcare necessitate revision of the current apprenticeship model of surgical training. Current methods of assessment such as examinations and logbooks are not criteria-based, so are subjective and lack validity and reliability. The objective feedback of technical skills is crucial to the structured learning of surgical skills. We review current publications about training and methods of assessment in microsurgery. Searches on PubMed using keywords (microsurgery, training, assessment, simulation, and skill) were used to retrieve relevant articles, and further cross-referencing was done to obtain more information. New methods of assessment that are objective include checklists, global rating scales (GRS), and dexterity analysis, which give feedback of technical skills during training. Vital (living), non-vital, prosthetic, and virtual reality simulation models can be used to train surgeons to a proficient level outside the operating theatre before they operate on real patients. After reviewing the current evidence we propose a curriculum for microsurgical training that starts outside the operating theatre. The surgical community should follow the example of other high-risk industries such as aviation, where continuous assessment on simulators is a part of training, but further research is necessary before such methods can be used for summative assessment and revalidation.

Keywords: Microsurgery; Training; Assessment; Skill; Simulation

Contents

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Introduction

Microsurgical techniques were first described over a century ago by Alexis Carrel who won the Nobel prize in 1911 for his pioneering work in blood vessel anastomosis.[1] In the 1960s huge advances were made in microsurgery, and Nakayama was the first to describe free tissue transfers in humans when he used intestinal segments to repair the cervical oesophagus.[2] Microsurgical techniques are essential in maxillofacial reconstructions,[3] and an adequate training curriculum is vital to ensure that it is practised well.

Current surgical training is based on the Halstedian apprenticeship model that was introduced over 100 years ago.[4,5] Training and progression depend on a variety of cases, workload, and subjective assessment by the tutor but, with current changes in healthcare (reduction in working hours, pressures on operating room efficiency, and the ethical considerations of training on patients), this needs to be revised. With the publication of medical errors and adverse events,[6,7] training and certifying bodies are under pressure to develop new ways to show evidence of a surgeon's competence to ensure quality. Operative competence cannot be assured on the basis of experience and exposure to sheer volume alone,[8,9] and specifically designed curricula with formal assessments in competency must coexist.[10] It is crucial for surgeons to be technically competent before entering theatre, and that the methods used for their assessment are robust.[11] Wass et al.[12] described the assessment of surgical skill as the "international challenge of the century for all involved in clinical competence testing".

We review current models of training and assessment in microsurgery, and report on the development towards a new curriculum.

Definitions

The Post Medical Education Training Board in the UK defines *assessment* as "The process of measuring an individual's progress and accomplishments against defined standards and criteria, which often includes an attempt at measurement. The purpose of assessment in an educational context is to make a judgement about mastery of skills or knowledge; to measure improvement over time; to arrive at some definitions of strengths and weaknesses; to rank people for selection or exclusion, or perhaps to motivate them."[13]

The purposes of assessment are to provide feedback and aid learning (formative, or low stakes assessment), and to examine or certify (summative, or high-stakes assessment).

Good assessment should be reliable, valid, educational, acceptable, and feasible in terms of cost effectiveness and delivery.[14]

A reliable test should give the same result if repeated (test-retest) or if a different assessor is used (inter-rater). Scores for reliability range from 0 (no reliability) to 1 (perfect reliability). An arbitrary, but generally accepted value for high-stakes examination is 0.8.

The five types of validity are defined in Table 1.[15]

Table 1
Types of validity.

Type of validity	Definition
Face validity	The chosen task resembles those that are performed during a surgical procedure in real life situation.
Content validity	The test actually assesses a specific skill, not other aspects such as anatomical knowledge.
Construct validity	Degree to which the test actually captures the skill level it was designed to measure (discriminates between novice and experts).
Concurrent/criterion validity	Extent to which a test yields same results as other measures of the same phenomenon, i.e. comparable with the current gold standard tool.
Predictive/outcome validity	Relates to future performance and transfer to the operating room.

Current methods of training in microsurgery

The operating theatre has been recognised as a poor classroom for the training of novice surgeons. It is expensive, stress levels cannot be controlled, and cases may not be suitable. In recognition of this institutions require trainees to attend a microsurgical course before entering the operating theatre. These courses vary in length and in the simulation models they use for practice.[16,17] There are no formal assessments and participants are given a certificate of completion rather than one of competency.[18] One study of trainees who attended a microsurgical course of 1 week's duration found that 60% had improved, 10% had remained the same, and 30% had got worse when assessed using global rating scales (GRS) and vessel viability.[19] Another study found that those completing a microsurgical course, including fellowships, were unable to complete vascular anastomosis at a satisfactory rate of patency.[20] Attendance of these courses and even theatre experience cannot lead us to presume that trainees have reached a certain level of proficiency.

Methods of assessment

Currently there are five methods of assessment in surgery and all vary in the degree of validity and reliability (Table 2).[15] Objective assessments to achieve Membership or Fellowship of the Royal Colleges in the UK are knowledge-based and do not assess technical ability. One study showed that there was no correlation between the American Board of Surgery In-Training Examination score and technical skill.[21]

The keeping of accurate logbooks is a requisite in the UK and they are a useful record of experience gained,[22] but

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Table 2
Technical skills assessment: available approaches.

Method	Reliability	Validity
Procedure lists with logs	N/A	Poor
Direct observation	Poor	Modest
Direct observation with criteria	High	High
Animal models with criteria	High	Proportional to realism
Videotapes	High	Proportional to realism

N/A = not applicable.

they record only exposure and not performance within the operating theatre, and therefore lack content validity.[15,23]

Using "time to complete" alone is a crude assessment as it is influenced by many factors and does not equate to quality. Time will improve with better decision-making and technical ability,[24] but should be used in context with other methods of assessment. Assessment by the supervisor within the operating theatre is subjective, not criteria-based, and therefore lacks reliability. Test–retest reliability is poor, and it has been shown that expert surgeons can disagree in their assessments, which shows poor reliability between observers.[15]

Data on morbidity and mortality are now widely used to increase transparency and patient choice, but such data are affected by many factors and should not be used alone. It is fortunate that cases of morbidity and mortality are rare, and large numbers of patients are required before significant differences are seen, which is too late. This emphasises the need for objective assessment of technical skill as a form of quality assurance.[25]

Checklists and global rating scales

Criteria-based assessments that use checklists and GRS are more objective. Checklists, which involve a candidate being marked against a set list of tasks are widely accepted and used in the Objective Structured Clinical Examination (OSCE).[26] The assessor becomes an observer of behaviour rather than an interpreter, which removes subjectivity.[27] However, the assessor cannot comment on whether the individual tasks were performed well or in the correct order, so it assumes that surgical procedures follow a predefined protocol. For this reason novices may perform better than an expert on a checklist as they breaks down the procedure into steps, whereas experts act automatically towards an end goal, which does not show construct validity.[28,29] (Kalu et al.[30] have adapted a checklist that can be used in end-to-end arterial anastomosis.)

GRS[27] consist of a number of important dimensions deemed by a group of senior surgeons to be important when completing a task (for example tissue handling), and are graded on a Likert scale with statements as anchor points (Grober et al.[31] have developed such a scale for microsurgery). They may be open to rater biases, which affect reliability,[14,29] but if assessors are trained to use the assessment forms, evidence shows that both GRS and checklists have validity, but GRS have consistently been found to be more reliable.[32]

Procedure-based assessment uses the above methods and also grades the ability of the trainee to carry out the whole procedure. Such forms can be found on the Intercollegiate Surgical Curriculum website,[33] and those relevant to maxillofacial microsurgery include raising fasciocutaneous radial forearm free flaps, and pectoralis myocutaneous flaps.

A disadvantage of this type of assessment is that the assessor must be present throughout, which is labour-intensive, but video recordings can be used to overcome this as assessment can be done at a convenient time, and also blinds the assessors. Unfortunately, it is still time consuming and costly in resources.

Hand motion analysis

Surgical skill has been described as 25% dexterity and 75% decision-making[34]; in microsurgery dexterity is even more important. The Imperial College surgical assessment device emits electromagnetic waves to track the position of sensors placed on the back of the surgeons hands (Fig. 1a and b).[35,36]

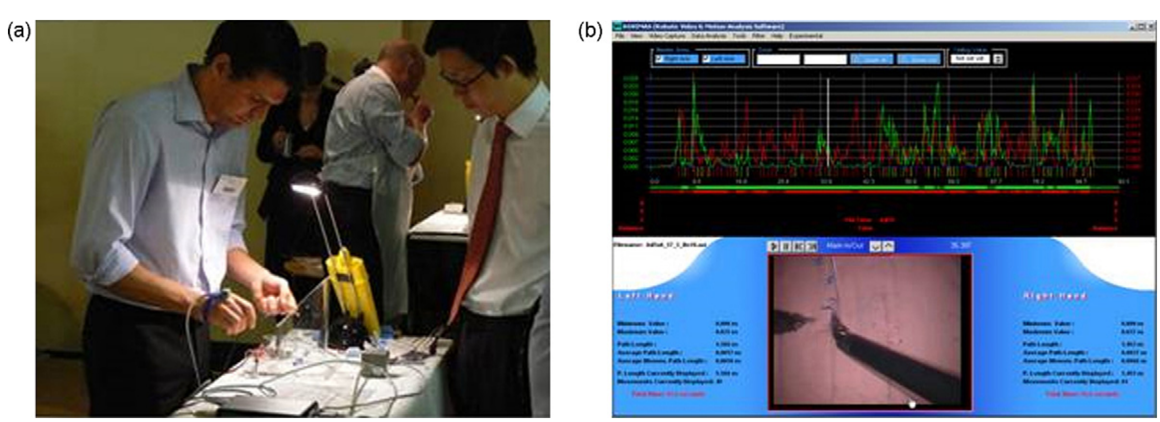

Fig. 1. (a) Imperial College surgical assessment device (ICSAD), and (b) dexterity results and facilities for video recording.

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Table 3
Validation of microsurgery models.

	Face validity	Content validity	Construct validity	Concurrent validity	Predictive validity
Non-living models					
Rubber practice pad	–	–	–	–	–
Surgical gauze	–	–	–	–	–
Silicone tubes	–	+	+	–	–
Coloured beads	–	+	–	–	–
Glove box model	–	+	–	–	–
Foliage leaf	–	+	++	–	–
Latex sheet/glove	–	+	–	–	–
Practice cardboard	–	++	++	–	–
Practice rat	–	+	–	–	–
PVC rat	–	+	++	–	–
Dexter	–	–	–	–	–
Suture covered rubber thread	–	–	–	–	–
Human placenta	+	+	–	–	–
Animal models					
Rabbit	+	–	–	–	–
Rat hind limb	+++	++	–	–	–
Tissue flaps in rats	+++	++	–	–	–
Perforator flaps in rats	++	–	–	–	–
Cervical area of rats	+	–	–	–	–
Cryopreserved rat vessels	++	++	++	+	–
Chicken wing arteries	+	++	–	–	–
Pig legs	++	++	+	+	–
Simulators					
Microvascular simulator	+	++	++	–	–
Boston dynamics inc. Surg simulator	++	++	+++	–	–
Algorithmic tools	+++	+++	++	–	–
Anastomotic trainer	–	–	+++	–	–
Hand motion analysis	+	+++	+++	–	–

The device runs from a standard laptop computer and measures time, total number of movements, and distance travelled for each hand. Its developers have also added a video recording facility to allow for objective assessment of the procedure at a later date. It has been shown to be an effective index of technical performance in open[37] and laparoscopic surgery,[38] and microsurgery, and has also correlated well with GRS and leak rates in vascular anastomosis.[39] Many studies have found it to be an objective, valid, and sensitive method of assessing technical skill that essentially eliminates the potential for examiner bias.[40,41]

Analysis of final product: patency rates and physiological function

A good technique, fast time, and satisfaction of the supervisor may not ensure good rates of patency.[42] The use of synthetic models to show rates of patency may add value to the assessment, but lack realism as normal clotting processes cannot be replicated.[43] One study using live rats showed that it took novice surgeons between 40 and 48 vessel anastomoses to achieve 100% patency (in the last 8 anastomoses done) 2 weeks after the procedure.[44] The use of patency rates is possibly the most valid and reliable way to train and assess surgeons, but it is time consuming and expensive.

Reznick showed that end product assessment on bench top models (in general surgery) correlated well with GRS, time taken, and year of training. Assessors do not need to watch the whole procedure and can make blinded assessments at the end, making it more feasible.[44]

Atkins et al.[19] used microvascular physiological function as a form of assessment after a microsurgical course. Harvested anastomosed rat vessels were subjected to increasing concentrations of noradrenaline and a final dose of potassium chloride. The amount that the vessel had contracted was used as a proxy for its viability despite not being measured directly. Again, this method of assessment is complicated and costly in resources, which questions its feasibility.

Learning curves

Objective assessments of junior trainees can be used to plot learning curves and to show progression, for example during a course.[45] They can also be used to compare novice performance with that of experts. Some studies have shown that novices need to do around 50 anastomoses in rat vessels to reach similar rates of patency to those of expert surgeons.[46–48] The documentation of learning curves can be used as feedback to focus training on particular weaknesses.

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Simulation models available for microsurgical training

Currently rats are the gold standard for microsurgical training because of their availability, resistance to infection,[49] and low cost,[50] but licenses required to keep animals, ethical considerations of training on animals, and cost, are limitations.[51–53]

Lannon et al.[54] split the different models used in microsurgical training into living and non-living models. The latter can be further split into non-vital (for example frozen chicken thighs), prosthetic (for example latex), and virtual reality. The authors commented that non-living models are advantageous because they are accessible, portable, and cheap. They have a favourable shelf life, and are low biological hazards and low-maintenance, but may not be as realistic as living models. The discussion by Chan et al. about the validity of the different models has been summarised in Table 3.[55]

More importantly, Grober et al. showed that those who trained on low fidelity synthetic bench top models did as well as those who had been trained on live rats,[56] and there have been similar findings in other aspects of surgery.[57] Novices can use low fidelity models to familiarise themselves with microsurgical techniques, and then refine their skills on higher fidelity or animal models before operating in theatre.[24,28,29] The use of prosthetic models reduces the number of animals used in training by up to 50%, and costs by 20%; efficiency and effectiveness of training can also be improved.[28–30]

Durability of skills training: intermittent training compared with intensive training

Studies have shown that performance improves immediately after intensive courses,[58–60] but that skills deteriorate with time.[61] Trainees may have to wait some time after a course before they can practise the skills in theatre, and this affects those rotating through various subspecialties that do not include microsurgery. Training in the laboratory on synthetic models can overcome this.

Grober et al. showed that opportunities to practise enhance the performance of trainees.[62] In his study surgical trainees were randomised into two groups: massed training (4 training sessions over a day) and distributed training (4 training sessions over 4 weeks). Those in the distributed training group performed better immediately after training and also retained their skills better than the massed group when assessed 1 month later. Other studies agree, and have concluded that having opportunities for repeated practise results in improved retention after a course[63]; longer lapses of time between opportunities to practise have a negative impact on retention.[64] Repeated practise also seems to be beneficial in real cases, for example surgeons who often do the same procedure have lower rates of morbidity and mortality than those who do not.[65,66]

Virtual reality

During microsurgical procedures the operator is immersed within a virtual environment by the use of the microscope, and this type of surgery lends itself well to practice using virtual reality. Haluk and Krummel[67] described it as a useful tool in the training of surgeons because it is risk-free and can be replicated infinitely. It can be stopped and started at will and adjusted for levels of difficulty. There are always opportunities for practice, and stress levels can be controlled. Feedback is reliable, immediate, and objective, and it avoids the ethical implications of training on animals or humans. Proficiency-based curricula (based on expert scores) that were developed on laparoscopic virtual reality simulators have been shown to be more effective than a standard box trainer in the training of novice laparoscopic surgeons,[68] and findings have been similar in endovascular,[69] and robotic surgery.[70]

Stanford University have developed a system that consists of a graphics workstation connected to a stereoscopic display. Real microsurgical instruments are used as input devices, and an electromagnetic tracking device is used to provide localisation (Fig. 2a and b).[71] The tracked instruments enable

(a) (b)

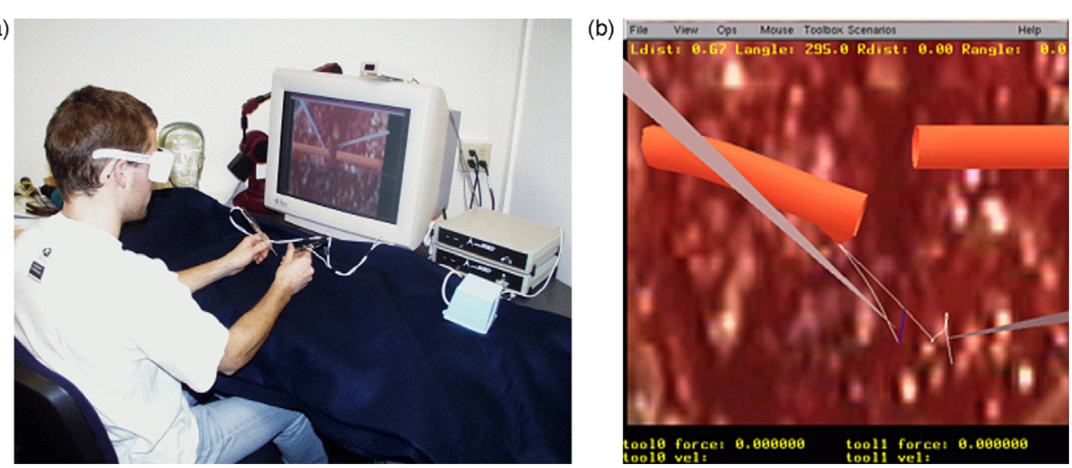

Fig. 2. (a) Set-up for virtual reality microsurgery, and (b) scene for interaction of vessel, forceps, and suture.

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Table 4
Proposed curriculum for microsurgical training.

Year of training	Model used	Formative assessment	Location	Timing
Core training year 1 (*3 years post-qualification*)	Basic Surgical Skills course	Summative Basic Surgical Skills course with formal assessment at end of course	Regional training centre	
Core training year 2 (*4 years post-qualification*)	Bench models	Formative Preparation and training for competency day as part of membership exam (see below)	Training hospital/regional deanery	2 × 6 monthly assessments in generic surgical skills
End of core surgical training (*4 years post-qualification*)	Competence day as part of Membership of the Royal College of surgeons	Summative Assessment of generic surgical skills such as suturing and knot tying. Pass/Fail	Regional training centre	Prior to entry into specialty training
Specialty training year 3–4 (*5–6 years post-qualification*)	Bench top microvascular prosthetic models	Formative Assessment using motion analysis demonstrating improvement in dexterity skills, in preparation for microsurgical course attempt to achieve expert scores	Training hospital/regional deanery	Yearly assessment in Microsurgical dexterity
Specialty training year 3–4 (*5–6 years post-qualification*)	Microsurgical course (1 week) using prosthetic and rat models	Summative Objective assessment of rat vessel anastomosis using motion analysis, Video GRS and checklists at end of course. Pass/Fail	Regional training centre	Prior to Oncology attachment
Specialty training year 5–7 and (*7–9 years post-qualification*)	Higher fidelity models (as they become available and maybe also VR) Whole procedure-based training and team training in simulated operating theatre. Real cases in theatre	Formative Formal end of year assessments on high fidelity models Continuous assessment on real procedures (GRS/checklists and video based blinded assessments)	Local training hospitals	Ongoing
Completion of specialty training	As part of Fellowship of the Royal Colleges	Portfolio of satisfactory assessment of technical skills during training		
Revalidation and Recertification (*throughout surgical training*)	Appropriate models and assessment modes at different stages of training	Part of portfolio throughout surgical training		

the user to do microsurgical anastomoses, and the system evaluates the surgeon's performance based on a number of objective variables,[72] but the validity of virtual reality, its role in surgical education, and its cost is yet to be determined. No doubt, with the rapid development of technology within this field, such simulators may have an important role in the future of surgical training.

Discussion

With the availability of the training tools discussed in this paper are available, formal curricula can be devised for the training and assessment of skills to start outside the operating theatre. Surgical skills could be assessed at yearly reviews as part of our current assessment with portfolio and logbook presentations. This will become more important in the current system of "revalidation and recertification" within the NHS in the UK.

At present, learning and teaching that occurs outside the operating theatre is mainly based on theory and knowledge. As surgeons we should be keen to employ training in technical skills outside the theatre. Technical skills laboratories need to be more widely available, and time for their use should be incorporated into the work schedule. They can be used for training and assessment of basic microsurgical skills, and can have an important role in the retention of surgical skill.

All training models and methods of assessment have their pitfalls when used alone, and it has been suggested that a combination of them should be used at different points in training.[73,74] Our proposed curriculum based on the current evidence available is shown in Table 4.

Microsurgical technique is a specialist skill and has therefore been omitted from core surgical training. Yearly formative assessments made in the third and fourth specialty years use low fidelity prosthetic models and are assessed using hand motion analysis, which makes this type of training and assessment more feasible at local hospitals. These models can be used in clinical skills laboratories throughout training for the development and retention of skills. Simulation models used in summative assessments at a more senior level need to be more valid and robust. Assessment at the end of the microsurgical course uses rat models and a number of assessment tools. During the first 2 years of specialty training departments should encourage trainees to attend courses that objectively assess a level of proficiency. As in the course on advanced trauma life support (ATLS) the aim is to demonstrate a certain level of competence, and not to prevent the trainee from being able to operate in theatre if a satisfactory level is not achieved. As trainees progress further, higher fidelity models or virtual reality can be used for training and assessment alongside objective assessments made on real patients.

Training in a whole procedure and in a team can take place in a *simulated* operating theatre[75]; the purpose again is similar to that of the ATLS course where actors are used to replicate the whole surgical team; the simulation model used, whether it is virtual reality or an animal model should be selected appropriately. This can aid training in technical skills as well as in teamwork, communication, judgement, and decision-making.

As oncological surgery is likely to be moved to cancer centres in the near future, trainees may need to undertake fellowships during specialty training or after its completion to ensure that they can gain the relevant competencies. We recognise that theatre experience is invaluable, and that training and assessment on simulation models should be used only to aid current methods of training and not to replace real operating time.

At first, setting up and running such a curriculum will be expensive, but we hope that it will result in trainees being better prepared before entering the operating theatre, and in the long term, tangible and intangible costs to both the hospital and the patient will be reduced. Further research into such a curriculum is needed to demonstrate its validity, reliability, and feasibility before it can be adopted, although linking it to an improvement in patient outcome (which should be the ultimate goal) will be difficult.

We have focused on competency training and assessment. This model has been criticised because competency can be seen at the beginning of a continuum towards expertise. As professionals we should aim to train towards levels of expertise, but this is difficult to define, and will form the scope of future research within our department.[75] We have also focused on procedural performance as an assessment of surgical ability, but we are aware that this is only one of many qualities that are necessary. Situational awareness, decision-making, task management, leadership, communication, and teamwork, are other attributes that have been described, and research into the development of objective assessments for these skills has been done.[76,77]

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