APS
Archives of Plastic Surgery

Topic

Research Priorities in Light of Current Trends in Microsurgical Training: Revalidation, Simulation, Cross-Training, and Standardisation

Rebecca Spenser Nicholas[1], Rudo N Madada-Nyakauru[2], Renu Anita Irri[2], Simon Richard Myers[3], Ali Mahmoud Ghanem[3]

[1]Department of Plastic Surgery, Royal London Hospital, London; [2]Imperial College London, London; [3]Academic Plastic Surgery Group, Barts and the London School of Medicine and Dentistry, London, UK

Plastic surgery training worldwide has seen a thorough restructuring over the past decade, with the introduction of formal training curricula and work-based assessment tools. Part of this process has been the introduction of revalidation and a greater use of simulation in training delivery. Simulation is an increasingly important tool for educators because it provides a way to reduce risks to both trainees and patients, whilst facilitating improved technical proficiency. Current microsurgery training interventions are often predicated on theories of skill acquisition and development that follow a 'practice makes perfect' model. Given the changing landscape of surgical training and advances in educational theories related to skill development, research is needed to assess the potential benefits of alternative models, particularly cross-training, a model now widely used in non-medical areas with significant benefits. Furthermore, with the proliferation of microsurgery training interventions and therefore diversity in length, cost, content and models used, appropriate standardisation will be an important factor to ensure that courses deliver consistent and effective training that achieves appropriate levels of competency. Key research requirements should be gathered and used in directing further research in these areas to achieve on-going improvement of microsurgery training.

Keywords Surgery, plastic / Microsurgery / Inservice training / Patient simulation / Education

Correspondence:
Ali Mahmoud Ghanem
Academic Plastic Surgery Group, Centre for Cutaneous Research, Barts and the London School of Medicine and Dentistry, Blizard Institute, 4 Newark Street, London E1 2AT, London, UK
Tel: +44-20-7882-7173
Fax: +44-20-7882-7171
E-mail: a.ghanem@qmul.ac.uk

No potential conflict of interest relevant to this article was reported.

Received: 23 Feb 2013 • Revised: 14 Mar 2013 • Accepted: 5 Apr 2013
pISSN: 2234-6163 • eISSN: 2234-6171 • http://dx.doi.org/10.5999/aps.2014.41.3.218 • Arch Plast Surg 2014;41:218-224

INTRODUCTION

Subsequent to the much-anticipated revalidation for doctors in the UK that began on 3 December 2012, it is now a priority for clinicians to be able to demonstrate competency, probity, and evidence of current medical knowledge and practice [1]. In the light of this need for revalidation, various surgical specialities have conducted audits to seek opinions on revalidation and the best way to assess clinicians' skills [2,3]. However, a survey of the literature addressing revalidation in the specific contexts of plastic surgery and microsurgery suggests that this area has not been sufficiently researched.

The importance of redressing this paucity of research becomes particularly clear when set against the backdrop of the wider review and restructuring of plastic surgery training in the UK that has been taking place during the past decade. This has led surgical educators to seek improved ways of developing and maintaining surgical skills [4]. As a result, validation and simulation are increasingly important educational components, with simulation providing a way to reduce risks to both trainees and patients whilst facilitating improved technical proficiency.

There is growing evidence for the value of 'cross-training', in which a skill is developed in a context that is different to that of its eventual practice, or a different skill is practised that leads to a related improvement in a desired area [5-7]. In particular, the high-skill element of microsurgery suggests that microsurgery simulations could have related benefits in other areas of plastic surgery and surgery in general. However, as yet, very little research exists assessing this hypothesis.

The systematic development of research agendas has been used to good effect to help shape research in various disciplines such as cancer research and medical education [8,9]. Nonetheless, research priorities for revalidation and cross-training particularly focused on microsurgery, although important, have not yet been defined. This is particularly significant given current economic constraints resulting in less funding opportunities for such research. Therefore, the aim of this review is to assess and highlight research priorities for revalidation and cross-training through an analysis of the salient factors.

REVALIDATION

Senior plastic surgeons, including consultants, associate specialists and staff grade doctors will have undergone microsurgery training during their formative years. Subsequent to completing their training, they will have had a varying extent of exposure to microsurgery based on their sub-specialities. Revalidation in microsurgery seeks to assess their current skill level and to identify any loss of skill since the completion of training. Importantly, assessment of senior clinicians should enable a safe threshold to be established that can be expected of a senior microsurgeon. Once this threshold is obtained, future assessments can be made comparing it to this level. For plastic surgical trainees, microsurgical exposure throughout training is imperative to allow the development of skill and ultimately also to lead to proficiency.

Appropriate revalidation requires sound assessment tools that adequately measure competence. Such tools necessarily look beyond logbook data and quantitative information to assess quality. Assessments used for the revalidation process need to be reproducible as well as being implementable and cost-effective [10-12]. The requirements for objective assessment methods of microsurgery have led to the development of several global rating scales (GRSs). These scales break down the microsurgery process into relevant components that have been found to contribute to the overall performance of the task. Notably, these GRSs have been found to be better measures of surgical competency than checklists or observed structured clinical examinations where trainees may perform better than experienced clinicians as they follow a step-by-step approach, whereas experienced surgeons execute the task fluidly, considering the whole procedure, and consequently may omit stages on the checklist but achieve a better overall outcome for the patient [13]. Videos allow skill assessment in a controlled environment [14] and as technology advances, different methods for assessing competency are becoming available, such as hand motion analysis (HMA). For example, the Imperial College Surgical Assessment Device uses motion sensors attached to the hands to assess hand movements and the length of time to complete a task [15]. This device has been shown to have applications in both laparoscopy and microsurgery [16]. Grober et al. [17] took this further by performing HMA in two live procedures; microsurgical reversal of vasectomy and vasectomy performed without a scalpel. They concluded that the results could be used objectively in assessing performance of a procedure.

Simulation as a tool for revalidation

As appropriate validation methods are sought, simulation is becoming an increasingly important component of surgery training. Modern technology means that higher fidelity training environments (i.e., training environments more similar to actual practice) are available [18]; in particular, recent developments raise the possibility of virtual reality environments [19]. Such virtual environments may be preferable to other simulations because they not only focus on technical proficiency but also the cognitive/clinical skills and the social/interactive skills that are needed in the surgical environment [20].

Simulations are particularly beneficial when used as a part of on-going skills maintenance and not just 'one-off' intensive courses. It has been shown that spacing training simulations and assessments over a longer timeframe rather than a condensed period of training leads to higher skill level. One study compared an intensive microsurgery course consisting of four sessions on the same day with once-weekly sessions of the same number of hours over a one-month period and found higher skill uptake in the latter [21]. In addition repeated practice over a longer period also leads to greater competency [22,23]. However, the current delivery of microsurgery training involves little follow-up to ensure that students who have attended a course are able to practice those skills (either in a simulated environment or clinical setting) in a sustained way. Consequently, the maximal benefit of the training intervention is not realised. Therefore, it has been suggested by Evgeniou and Loizou [22] and Balasundaram et al. [16] that microsurgery assessment should become an integral part of on-going trainee competency evaluation once a trainee enters a training programme. At more senior levels, simulation may be used as an assessment tool to ensure continued levels of competence among surgeons, as part of the process of revalidation.

Assessing revalidation and simulation

Revalidation is important when it is seen not as a way to entrap clinicians but as part of an on-going drive to improve patient care, safety, and service delivery. In an audit of Scottish ophthalmologists, only 33% felt prepared for the revalidation process [24]. However, within the last year, physicians have received increased information both in terms of why it is important and how the process functions. Views on revalidation from plastic surgeons surveyed concentrated on how consultants felt about e-learning being used as a tool to facilitate revalidation and continuous professional development [2]. The majority wanted e-learning to support their revalidation and modules relating to microsurgery could be included to facilitate this. Satterwhite et al. [25] piloted an interactive web-based microsurgery curriculum for trainees, finding improved knowledge and skill in microsurgical tasks.

Continued practicing of skills is important at all levels, particularly for trainees. Simulation provides a means for maintaining skills that might otherwise not be regularly performed, which is important given that the longer the gap between practice sessions, the greater the loss of skill. Such sustained development would contribute to improved proficiency in microsurgery, especially where regular practice of microsurgery tasks is limited. Although such early training would involve co-ordination at deanery levels, designated training times and some financial input, the benefits of such programmes may be significant. Laparoscopic training programmes with follow-up sessions in different hospitals already exist, benefitting general surgery registrars interested in colorectal surgery [26]. The success of such interventions suggests similar opportunities may be both feasible and beneficial in microsurgery.

CROSS-TRAINING

Many of the training models that underpin plastic surgery training interventions follow a 'practice makes perfect' theory of skill development [27], the roots of which date back to over a century ago. These emphasise understanding, refinement and repeated reinforcement as the primary means for skills development [28]. Although being old does not necessarily render such theories obsolete, it does suggest that given educational advances and improved understanding of skill acquisition, there may be a benefit in exploring other models. Furthermore, evidence suggests that whilst traditional methods of reinforced learning may improve performance in the short-term, they can degrade performance in the long-term [29].

A preliminary study about cross-training in medicine has suggested the benefits it may offer. Bardes et al. [5] found improved visual diagnostic skills in medical students who participated in art observation workshops. This study is interesting because it built on previous work that suggested a seemingly unrelated area could prove a fruitful context in which to hone skills in observing and assessing visual details [30,31]. These skills were then transferred to a medical context with the result that students performed better than those who had not received such training.

The benefits of cross-training are well attested in sport science, whether it is those of dance training for cross-country skiers [6], or the now well-known improvements that Pilates brings to many sports [7]. Cross-training provides variation that helps development in a more holistic way, and increasing task variance in training improves the application of a skill where conditions are more variable [29]. Cross-training also affords the opportunity to focus training on a particular skill or muscle group that otherwise might not be isolated and improved through conventional training.

A brief article in the *Journal of the American Society of Plastic Surgeons* suggests the potential benefits of cross-training particularly for plastic surgery, observing: theoretically plastic surgeons are the ultimate cross-trainers because we operate on the entire body and have many dimensions to our speciality [32].

A study of note that suggests significant benefits took a large cohort of patients (over 110,000) and showed that orthopaedic surgeons who had performed a high volume of hemiarthroplasty operations had significantly lower mortality rates in a quite different procedure–the total hip arthroplasty, than those who had not performed a hemiarthroplasty in the past year. This study is interesting because of its clear evidence that surgical skills are transferable [33]. Furthermore, multi-disciplinary simulation of the theatre environment has been shown to help develop non-technical skills and better prepare clinicians for less-common scenarios such as surgical emergencies [34].

Technical skills and non-technical skills

The distinctive emphasis that microsurgery places on advanced technical skills gives it particular challenges for training. Currently, there is no universalised system by which surgical skills are assessed, but generally there are considered to be three broad categories: cognitive/clinical skills, technical skills, and social/interactive skills [35]. The distribution of these skills is debated and depends upon the specialty and the particular operation being undertaken [36]. What is clear is that both technical skills and non-technical skills such as communication are vital; a recent study found that poor communication was a causal factor in 43% of errors in surgery [37].

Traditionally, surgical skills have been taught in a form similar to apprenticeships–a model that still underpins the basic structure of surgical training. Assessment of surgical technique has been and remains largely subjective, and it has been difficult to assess the relationship between dexterity and successful surgical outcomes [38]. However, the validity of the 'learning by doing' approach as a predominant training methodology is becoming increasingly questioned for not representing best practice and for the significant variation in training experience among trainees [39].

Non-technical Skills for Surgeons assesses four categories of such skills–decision making, situational awareness, communication & teamwork, and leadership [40]. This being said, the majority of training interventions do not focus on these 'softer' skills, and yet (as noted above in the art observation workshops to augment visual diagnostic skills), these are areas where cross-training may be beneficial [41]. In particular, it is highly likely that other professions exist in which expertise in these specific areas plays a more important role in professional practice. For example, could surgeons learn from the military about improving teamwork or situational awareness [42] and from teachers about better communication? If these areas are important for surgical roles, then why not assess surgical training in these areas against other professions' 'gold standards' and see whether there are opportunities to improve?

The intricate nature of microsurgery places a particular emphasis on technical proficiency and psychomotor aptitude and development. Consequently, whilst microsurgical training interventions do improve microsurgery performance, a significant factor affecting the degree of improvement is the psychomotor aptitude of the individual [43]. However, practicing intricate skills over a sustained period can also serve to improve psychomotor aptitude as neural pathways become better adapted to a particular function [44]. Consequently, the intricate nature of microsurgery, when performed regularly, may well serve to improve coordination and dexterity that would offer wider benefits to non-microsurgery elements of plastic surgery or surgery in general.

Assessing cross-training

Cross-training is extensively employed in areas outside of medicine and provisional research surveyed above suggests sufficient benefits to microsurgery to warrant making it a priority for research. A coherent and robust research agenda informed by expert opinion both in cross-training and plastic surgery training interventions would help to focus next steps. Whilst considering cross-training as a new training avenue in surgery, it is also worth reflecting on some important considerations that may help guide further analysis.

First, there are two aspects that need to be balanced. On the one hand, the strength of cross-training lies precisely in its variation from the context that the skill in practice will be performed in. On the other hand, transfer of learning (whether intellectual or motor skills) is dependent on accurate contextualisation in the training environment [45,46]. Consequently, as in the earlier mentioned study of art and visual observation, it is important that cross-training is set in the context of how the skill being developed will apply to practice; this aids both acquisition of the skill and long-term retention [47].

Secondly, it is perhaps worth considering the training in intellectual skills and the mastery of perceptual-motor skills as requiring distinct approaches. Psychologists have been able to describe the psychological substrates of perceptual-motor skills in a way that has not yet been possible for intellectual skills. Consequently, whilst we are able to talk of factors like 'muscle memory' in motor skill development, intellectual development still requires significantly more work to reach the same level of understanding [48]. Therefore, cross-training principles that build on advances in physical training methodology may be appropriate for motor skills, but links to development of intellectual skills need more careful thought.

STANDARDISATION

The need for training in microsurgical techniques crosses several surgical specialties such as oral and maxillofacial, plastic, cardiovascular, neurosurgical, vascular and urological surgery, with a wide variety of basic and advanced microsurgical courses available worldwide. Consequently, this calls for the establishment of an objectively measurable level of competency in a simulated environment that should be reached before entering the operating room.

The limited time, resources and opportunities to practice microsurgical technique in clinical settings, along with the serious consequences of failure, have led to the establishment of microsurgical training courses. Reviews of microsurgical training centres worldwide shows that basic microsurgery courses range in duration and intensity from 20 to 1,950 hours [49]. On average, a basic microsurgical training course lasts 40 hours (5 days) costing $1,500 (USD) [49]. The benefit of these courses is well established, and there is evidence that it is more efficacious to take part in such shorter more intense courses than to learn sporadically over a long period of time [50]. This effect seems to be related to the amount of training given, as interrupting the training sessions promoted deeper learning experience in skills learned over a one-day (8-hour) course [21]. That said, given the large variations in course durations and intensity, it would be helpful to have a basic standard to compare and contrast the relative benefits in training outcomes.

Standardisation of microsurgery training models

Microsurgery training courses depend on a variety of training models to practice on. Some courses use prosthetic models, such as a latex glove model and Penrose drains. Other courses use non-living animal models such as the cryo-preserved rat aorta and the chicken thigh model. Many others use live models such as anesthetized rats as a high fidelity model to train on. Prosthetic models have the advantage of portability, simplicity –minimal ethical issues or maintenance required– and the avoidance of using biologically hazardous material. The tissue experience of such models, however, is varied and the predictive validity of their use has not yet been established. In contrast, non-living animal models provide a more realistic tissue handling experience without ethical issues. However, as in synthetic tissues, the end product assessment of these models is doubtful, as vessel patency is not easily verified. Lastly, the use of live models in some courses, such as Columbia University in the US and Northwick Park in the UK, provides the most realistic simulation of microvascular anastomosis for students as well as the possibility of immediate assessment of anastomosis bleeding and vessel patency. Their high cost and ethical concerns remain prohibitive factors for their wide dissemination [51].

While there are clear advantages of using living models, it is important to take into account the cost effectiveness and ethics of using them. In some countries, namely the UK, it can be difficult to obtain ethical approval to use living models when there is an effective substitute to the procedure. Although there is already some evidence showing that novices performed just as well on prosthetic models in microanastomosis of tubal structures [51], a fully predictive validation of non-living model simulation-based training has not been established yet. With current challenges to microvascular anastomosis training in the clinical setting or with living animal models, it is important to establish standard guidelines about the extent, timing and adequacy of models used in training interventions and their relative merits and weaknesses.

Standardisation of training curricula–establishment of competency training thresholds

The minimum level of competency before moving to a clinical setting is postulated to be obtaining a patency level of above 80% using vessels of a similar caliber in a laboratory setting [50]. Both the patency rate and the speed at which it is achieved are important. The time to complete anastomosis is particularly relevant due to the impending chance of ischemic injury to the vessel and tissue [50]. This should be taken into account when assessing the minimum level of competency. Currently, microsurgical training courses offer a certificate of completion rather than a certificate of competency [52]. In the US, the minimum required hours for certification is 40 hours [52]. Within that period of time, some students may reach the level of competency while some may not. In addition to patency rate and time to complete the procedure, there are different methods of assessing students' skills during a training course. These include objective assessment tools: the Objective Structured Assessment of Technical Skill [53], as well as GRSs and HMA, both discussed earlier [54]. Most objective methods of assessment are able to demonstrate construct validity. However, the establishment of competency training thresholds for each of these assessment methods along with their predictive validity is still lacking [54].

The preceding discussion has highlighted various issues to consider before standardisation of microsurgical education can be achieved. Microsurgical training courses still vary significantly in length, models used, cost, content and competency achieved. A standardised multimodal assessment protocol along with appropriately defined competency levels for each stage of training will be important steps before the delivery of consistent, reproducible and effective training curricula are achieved.

CONCLUSIONS

As microsurgery training research seeks to improve skill acquisition, maintenance and development, revalidation, cross-training and standardisation are important priorities for microsurgery educationalists. The importance of these areas is accentuated when they are considered in the current political and economic climate affecting medical careers on both sides of the Atlantic where working hours have been reduced and demonstrable return on investment in training is expected.

The limited opportunity that many surgeons have to maintain their microsurgical skills emphasises the importance of revalidation, and in particular, revalidation done in a way that is seen to improve patient safety and service provision. Secondly, as new training methodologies are uncovered in non-medical fields, the rewards of cross-training highlighted here suggest that novel avenues of training in microsurgery could augment competency in both technical and non-technical skills. Thirdly, whilst the choice and availability of microsurgery training interventions is important, appropriate standardisation is required to ensure that consistent standards are achieved through these courses. Each of these areas reviewed suggest these are timely research priorities for microsurgery education with significant potential benefits.

REFERENCES

1. General Medical Council. Registration and licensing: revalidation [Internet]. London: General Medical Council; c2013 [cited 2012 Dec 28]. Available from: http://www.gmc-uk.org/doctors/revalidation.asp.
2. Stevens RJ. Do consultants want e-learning in plastic surgery for continuing professional development and revalidation? J Plast Reconstr Aesthet Surg 2011;64:e50-2.
3. Rogers SN, Lowe D. British Association of Oral and Maxillofacial Surgeons first national audit in support of revalidation. Br J Oral Maxillofac Surg 2011;49:478-9.
4. Moulton CA, Dubrowski A, Macrae H, et al. Teaching surgical skills: what kind of practice makes perfect? a randomized, controlled trial. Ann Surg 2006;244:400-9.
5. Bardes CL, Gillers D, Herman AE. Learning to look: developing clinical observational skills at an art museum. Med Educ 2001;35:1157-61.
6. Alricsson M, Werner S. The effect of pre-season dance training on physical indices and back pain in elite cross-country skiers: a prospective controlled intervention study. Br J Sports Med 2004;38:148-53.
7. Kloubec JA. Pilates for improvement of muscle endurance, flexibility, balance, and posture. J Strength Cond Res 2010; 24:661-7.
8. Robotin MC, Jones SC, Biankin AV, et al. Defining research priorities for pancreatic cancer in Australia: results of a consensus development process. Cancer Causes Control 2010; 21:729-36.
9. Kilian BJ, Binder LS, Marsden J. The emergency physician and knowledge transfer: continuing medical education, continuing professional development, and self-improvement. Acad Emerg Med 2007;14:1003-7.
10. Aggarwal R, Moorthy K, Darzi A. Laparoscopic skills training and assessment. Br J Surg 2004;91:1549-58.
11. Selber JC, Chang EI, Liu J, et al. Tracking the learning curve in microsurgical skill acquisition. Plast Reconstr Surg 2012; 130:551e-8e.
12. Temple CL, Ross DC. A new, validated instrument to evaluate competency in microsurgery: the University of Western Ontario Microsurgical Skills Acquisition/Assessment instrument. Plast Reconstr Surg 2011;127:215-22.
13. Kalu PU, Atkins J, Baker D, et al. How do we assess microsurgical skill? Microsurgery 2005;25:25-9.
14. Jabbour N, Sidman J. Assessing instrument handling and operative consequences simultaneously: a simple method for creating synced multicamera videos for endosurgical or microsurgical skills assessments. Simul Healthc 2011;6:299-303.
15. Datta V, Mackay S, Mandalia M, et al. The use of electromagnetic motion tracking analysis to objectively measure open surgical skill in the laboratory-based model. J Am Coll Surg 2001;193:479-85.
16. Balasundaram I, Aggarwal R, Darzi LA. Development of a training curriculum for microsurgery. Br J Oral Maxillofac Surg 2010;48:598-606.
17. Grober ED, Roberts M, Shin EJ, et al. Intraoperative assessment of technical skills on live patients using economy of hand motion: establishing learning curves of surgical competence. Am J Surg 2010;199:81-5.
18. Schoffl H, Froschauer SM, Dunst KM, et al. Strategies for the reduction of live animal use in microsurgical training and education. Altern Lab Anim 2008;36:153-60.
19. Berkley J, Turkiyyah G, Berg D, et al. Real-time finite element modeling for surgery simulation: an application to virtual suturing. IEEE Trans Vis Comput Graph 2004;10:314-25.
20. Meier AH, Rawn CL, Krummel TM. Virtual reality: surgical application: challenge for the new millennium. J Am Coll Surg 2001;192:372-84.
21. Grober ED, Hamstra SJ, Wanzel KR, et al. Laboratory based training in urological microsurgery with bench model simulators: a randomized controlled trial evaluating the durability of technical skill. J Urol 2004;172:378-81.
22. Evgeniou E, Loizou P. Simulation-based surgical education. ANZ J Surg 2013;83:619-23.
23. Sadideen H, Hamaoui K, Saadeddin M, et al. Simulators and the simulation environment: getting the balance right in simulation-based surgical education. Int J Surg 2012;10:458-62.
24. Megaw R, Rane-Malcolm T, Brannan S, et al. Revalidation and electronic cataract surgery audit: a Scottish survey on current practice and opinion. Eye (Lond) 2011;25:1471-7.
25. Satterwhite T, Son J, Carey J, et al. Microsurgery education in residency training: validating an online curriculum. Ann Plast Surg 2012;68:410-4.
26. Torkington J, Williams G. Training the trainees will improve uptake of laparoscopic colorectal surgery. Colorectal Dis

2010;12:707-8.
27. Stefanidis D, Arora S, Parrack DM, et al. Research priorities in surgical simulation for the 21st century. Am J Surg 2012; 203:49-53.
28. Bryan L, Harter N. Studies on the telegraphic language: the acquisition of a hierarchy of habit. Psychol Rev 1899;6:345-75.
29. Schmidt RA, Bjork RA. New conceptualizations of practice: common principles in three paradigms suggest new concepts for training. Psychol Sci 1992;3:207-17.
30. Edmonds K, Hammond MF. How can visual arts help doctors develop medical insight? Int j Art Des Educ 2012;31: 78-89.
31. Dolev JC, Friedlaender LK, Braverman IM. Use of fine art to enhance visual diagnostic skills. JAMA 2001;286:1020-1.
32. Bajaj AK. Cross-training in plastic surgery [Internet]. Arlington Heights: Plastic and Reconstructive Surgery (Journal of the American Society of Plastic Surgeons); 2012 Nov 19 [cited 2014 Feb 1]. Available from: http://journals.lww.com/plasreconsurg/blog/PRSonallySpeaking/pages/post.aspx?PostID=120.
33. Ames JB, Lurie JD, Tomek IM, et al. Does surgeon volume for total hip arthroplasty affect outcomes after hemiarthroplasty for femoral neck fracture? Am J Orthop (Belle Mead NJ) 2010;39:E84-9.
34. Milburn JA, Khera G, Hornby ST, et al. Introduction, availability and role of simulation in surgical education and training: review of current evidence and recommendations from the Association of Surgeons in Training. Int J Surg 2012;10: 393-8.
35. Aucar JA, Groch NR, Troxel SA, et al. A review of surgical simulation with attention to validation methodology. Surg Laparosc Endosc Percutan Tech 2005;15:82-9.
36. Spencer F. Teaching and measuring surgical techniques: the technical evaluation of competence. Bull Am Coll Surg 1978; 64:9-12.
37. Gawande AA, Zinner MJ, Studdert DM, et al. Analysis of errors reported by surgeons at three teaching hospitals. Surgery 2003;133:614-21.
38. Darzi A, Smith S, Taffinder N. Assessing operative skill. Needs to become more objective. BMJ 1999;318:887-8.
39. Barnes RW. Surgical handicraft: teaching and learning surgical skills. Am J Surg 1987;153:422-7.
40. Yule S, Flin R, Paterson-Brown S, et al. Development of a rating system for surgeons' non-technical skills. Med Educ 2006;40:1098-104.
41. Beard JD. Assessment of surgical skills of trainees in the UK. Ann R Coll Surg Engl 2008;90:282-5.
42. Friedman L, Leedom DK, Howell WC. Training situational awareness through pattern recognition in a battlefield environment. Mil Psychol 1991;3:105-12.
43. Nugent E, Joyce C, Perez-Abadia G, et al. Factors influencing microsurgical skill acquisition during a dedicated training course. Microsurgery 2012;32:649-56.
44. Van Herzeele I, O'Donoghue KG, Aggarwal R, et al. Visuospatial and psychomotor aptitude predicts endovascular performance of inexperienced individuals on a virtual reality simulator. J Vasc Surg 2010;51:1035-42.
45. Singley MK, Anderson JR. The transfer of cognitive skill. Cambridge, MA: Harvard University Press; 1989.
46. Kramer AF, Strayer DL, Buckley J. Development and transfer of automatic processing. J Exp Psychol Hum Percept Perform 1990;16:505-22.
47. Ferguson MC, Rice MS. The effect of contextual relevance on motor skill transfer. Am J Occup Ther 2001;55:558-65.
48. Rosenbaum DA, Carlson RA, Gilmore RO. Acquisition of intellectual and perceptual-motor skills. Annu Rev Psychol 2001;52:453-70.
49. Wokes J. Microsurgery training courses: a review. Face Mouth Jaw Surg 2012;2:12-5.
50. Martins PN, Montero EF. Basic microsurgery training: comments and proposal. Acta Cir Bras 2007;22:79-81.
51. Grober ED, Hamstra SJ, Wanzel KR, et al. The educational impact of bench model fidelity on the acquisition of technical skill: the use of clinically relevant outcome measures. Ann Surg 2004;240:374-81.
52. Studinger RM, Bradford MM, Jackson IT. Microsurgical training: is it adequate for the operating room? Eur J Plast Surg 2005;28:91-3.
53. Martin JA, Regehr G, Reznick R, et al. Objective structured assessment of technical skill (OSATS) for surgical residents. Br J Surg 1997;84:273-8.
54. Grober ED, Hamstra SJ, Wanzel KR, et al. Validation of novel and objective measures of microsurgical skill: Hand-motion analysis and stereoscopic visual acuity. Microsurgery 2003; 23:317-22.