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Review

Surgical training technology for cerebrovascular anastomosis

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ABSTRACT

Cerebrovascular anastomosis (for example in the management of Moyamoya disease or complex aneurysms) is a rarely performed but essential procedure in neurosurgery. Because of the complexity of this technique and the infrequent clinical opportunities to maintain skills relevant to this surgery, laboratory training is important to develop a consistent and competent performance of cerebrovascular anastomosis. We reviewed the literature pertaining to the training practices surrounding cerebrovascular anastomosis in order to understand the ways in which trainees should best develop these skills. A wide variety of training methods have been described. These may be classified into five general categories, according to training materials used, being synthetic material, living animal, animal carcass, human cadaver, and computer simulation. Ideally, a novice begins training with non-biological material. After gaining sufficient dexterity, the trainee will be able to practice using biological materials followed by high fidelity models prior to actual surgery. Unfortunately, the effectiveness of each model has generally, to our knowledge, only been judged subjectively. Objective quantification methods are necessary to accelerate the acquisition of competence.

1. Introduction

Vascular anastomosis is one of the most difficult skills to acquire in neurosurgery. The application of these techniques to treatment of some cases of Moyamoya disease, complex aneurysms and skull base tumors is likely to continue for the foreseeable future [1–3].

Because bypass surgery is infrequently used in clinical practice, it is difficult for novice surgeons to develop and maintain skills through opportunistic surgery [1]. Moreover, competent performance in other techniques in neurosurgery does not translate to the techniques of vascular anastomoses. To this end, aspiring cerebrovascular neurosurgeons require both an appropriate mentor and a commitment to appropriate laboratory training [1,2].

The importance of laboratory training was frequently emphasized in plastic and reconstructive surgery in the 20th century and a range of training models were developed [3–10]. Subsequently training scenarios were adopted for the education of neurosurgeons [11,12]. For training models to be valid to the performance of intracranial vascular anastomosis they need to be effective in improving manual dexterity and closely conform to the actual surgery. Unfortunately, the effectiveness of different models has been consistently judged subjectively without objective validation.

In order to understand how best to train for this surgery, we reviewed the literature regarding training models for bypass surgery and conducted summaries and analyses for these previously presented cases.

2. Search strategy

A literature review was performed to review training models for cerebrovascular anastomosis. The date of the final search was January 2013. Scopus was searched using the following keyword terms: "neurosurgery" AND/OR "anastomosis" AND "train*". Results were narrowed to the full text of relevant papers written in English. Additional useful articles identified from reference lists were also included. A review for previously presented training models was conducted and future developments in training models were discussed.

3. Conventional training in microsurgery

Microsurgical training using rats has been the most common training method since the development of microsurgery

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Table 1
Training models using living rats modified for cerebrovascular anastomosis

Authors, year	Site	Contents	Remarks
Kanazawa and Teramoto [17]	Cervical, femoral	Instruction of tissue dissection and anastomosis on cervical and femoral vessels	Importance of proper dissection
Matsumura et al. [62]	Cervical	Side to side anastomosis between cervical ICA and ECA	Fine anastomosis on thin vessels
Menovsky [63]	Cervical, femoral	Anastomosis through craniotomy on artificial skull (cast model)	Anastomosis in deeper field
Matsumura et al. [64]	Femoral	Side to side anastomosis between femoral artery and vein	Complicated anastomosis

ECA = external carotid artery, ICA = internal carotid artery.

[4,10,13–15]. This approach still remains pivotal for neurosurgeons to improve their fine motor skills. The outstanding advantage of this model is the similarity of rat vessels to small human cerebral arteries in terms of texture and haptic qualities. This also extends to physiological conditions including pulsation and coagulability [16]. Some authors have modified training methods using rat models to develop microsurgical competence beyond that of the vascular anastomosis (Table 1). Kanazawa et al. emphasised that it is important to learn proper technique for tissue dissection as well as anastomosis [17]. However, this animal model has several drawbacks. Recently, mounting ethical campaigns for the minimisation of animal use in experiments have made it more difficult to use rats or other live animals for surgical training purposes. Practical concerns are also important: the number of facilities capable of housing rats is limited and purchasing rats is costly. These issues have accelerated the development of simulation training models.

4. Substitutive training with synthetic material

In any fields requiring fine motor skill, it is essential for novices to repeatedly practice basic skills so that they can gain and maintain minimum standards. Proficient competent performance is focused mainly on automatic striatum/cerebellar functions rather than cortical functions [18]. To store basic procedural dexterity knowledge in the striatum, trainees should repeatedly practice basic skills. Since 1980, it has been emphasised in both hand surgery and plastic surgery that daily training using synthetic materials is convenient and important in terms of gaining manual dexterity, and many training models were thus developed [3,5,6,19–32]. The key aspects of these models is that they are economical, accessible and simple, making it easy to repeat and assess performance. Additionally, there is no use of living animals [33]. Moreover, for novice training, there are no statistically significant differences in the degree of training effectiveness between a high-fidelity model group (cadaver) and a low-fidelity model group (synthetic material) [34]. Accordingly, simulation training using synthetic material is more suitable for novice trainees, but is likewise effective for specialists to maintain their dexterity throughout their career [34]. In the last decade, the importance of this training has begun to gain recognition in neurosurgical circles as well, and several training models for neurosurgeons have subsequently been presented (Table 2). As in plastic surgery, the ideal training allows repetition so that trainees can achieve dexterity in basic skills, such as correct suture placement and knot tying [35]. Moreover, one specific need for neurosurgical training models is the performance of anastomosis in a deep surgical field through a narrow corridor [36,37]. Ishikawa et al. were able to model a high-fidelity artificial skull and brain using a selective laser sintering method for the training of deep anastomoses in an environment closer to a real surgical setting [12]. However, this model, which utilised synthetic materials, continues to be surrounded by limitations, due to the lack of focal fidelity from the biological point of view.

5. Roles of dead animals

Practice anastomoses using biological materials before surgery on living rats can be performed on dead animals. This should minimise the time taken to acquire competence on living rat anastomoses [25,38–40]. Vessels harvested from animals killed for other purposes (such as other experiments, chicken wings) are ideal materials, particularly for trainees who have limited access to living rats. The vessels from chicken wings or legs are commonly used [8,9,11,41–44]. Other biological materials, such as cryogenically preserved rat vessels [45], turkey carotid arteries [39] and porcine coronary arteries [46], have likewise been demonstrated. A summary of these training models, which have been published for cerebrovascular anastomosis, is shown in Table 3. The merits of these models are the low cost and absence of animal ethical issues. Disadvantages are that animal vessels are less accessible than synthetic materials and do not sufficiently simulate the physiological situation, for example, pulsatility and coagulability. To approach the physiological situation with the use of dead animal models, it has been proposed to connect the relevant vasculature to a closed circulation circuit filled with whole blood and providing circulation with an infusion pump [39,46]. However, this system is expensive and fails to simulate normal coagulation due to the need to anticoagulate the circuit. Although this model has vessel texture similar to human vessels, and is well suited to the development of manual dexterity, it does not utilise actual surgical anatomy.

Table 2
Training models using synthetic material for cerebrovascular anastomosis

Authors, year	Materials	Contents
Matsumura et al. [65]	Practice card with silicone tubes	Anastomosis on very small-caliber silicone tubes in diameters of 0.3, 0.5, or 0.7 mm
Indo et al. [35]	Table-top microscope, 10-0 nylon suture and gauze	Knot tying and untying with suture needle
Ishikawa et al. [12]	Artificial brain and skull	Deep anastomosis in high-fidelity setting
Matsumura et al. [66]	Practice card with silicone tubes	Anastomosis on small-caliber silicone tubes in diameters of 0.3, 0.5, 1.0, or 2.0 mm
Takeuchi et al. [36]	Mannequin head with water balloons and clay	Deep anastomosis in simple and economical setting
Inoue et al. [37]	Tissue box with 2 $\times$ 2 cm hole and 6.5 cm depth	Deep anastomosis in simple and economical setting
Inoue et al. [67]	Desk-type microscope, 10-0 nylon suture and gauze	Knot tying under fixed and maximum magnification ($\times$20)

Table 3
Training models using vessels harvested from animals for cerebrovascular anastomosis

Authors, year	Animals and parts	Remarks
Olabe [41]	Fresh chicken wing	With saline solution infused using serum infuser
Colpan et al. [39]	Turkey neck	With fluids ranging from simple water to whole blood infused using infusion pump with pulsation
Hino [11]	Chicken wing	Without infusion
Ayoubi et al. [68]	Human placenta	Without infusion

Table 4
Training models using human cadaver for cerebrovascular anastomosis

Authors, year	Bypass types	Remarks
Russin et al. [51]	CCA-RA-MCA bypass	Fresh cadaver pressurization model
Olabe et al. [48]	Various EC-IC and IC-IC bypasses	Human cadaver brain infusion skull model
Olabe et al. [50]	Various EC-IC and IC-IC bypasses	Human cadaver brain infusion model
Aboud et al. [49]	STA-MCA vascular repair	Cadaver model with dynamic filling of the cerebral vasculature with colored liquid and clear fluid filling of the arachnoid cisterns

CCA = common carotid artery, EC = external carotid artery, IC = internal carotid artery, MCA = middle cerebral artery, RA = radial artery, STA = superficial temporal artery.

6. The pursuit of anatomical fidelity

Some reports emphasise that anastomosis training using human cadavers is more efficient and effective for learning bypass surgery, especially high flow bypass (Table 4). Certainly, anatomical accuracy should improve training quality due to its face validity. Sidhu and colleagues revealed in their comparative study that training in a high-fidelity circumstance (human cadaver) was more efficient for gaining fine neurosurgical motor skills than training in a low-fidelity model (synthetic material) [47]. Through this model, trainees can learn an actual surgical procedure comprehensively from tissue dissection to anastomosis in a high-fidelity setting and improve their dexterity. However, there are disadvantages with this approach, including costliness, restriction of purchase, hardening of tissue, and lack of circulation and coagulability. Some countermeasures to these disadvantages have been reported. Olabe and colleagues presented a cadaver head model where they combine a skull which can be repeatedly used with a brain, which is more easily obtained than a whole body [48]. An infusion or pulsation model to recreate circulation can be incorporated [49–51].

7. Utility of industrial technology

Unfortunately, it is very difficult for neurosurgeons to have the opportunity to practice bypass surgery via the use of cadavers. Due to this limitation, current developments have centred around the use of engineering based training models. These models can be approximately divided into two categories. One is an artificial simulator, constructed from various synthetic materials via the use of a selective laser sintering method or the conductance of prototyping, in accordance with individual patient data [12,52,53]. This model is capable of offering surgeons a chance to simulate individual complicated surgeries preoperatively, as well as providing a similar anatomy to cadaver training. However, these systems still need to be physiologically improved in terms of tissue texture or the physiological characteristics of vessels. Ishikawa and colleagues proposed preparing vessels separately in their high-fidelity model [12]. Another engineering based training system is computer simulation in three dimensional (3D) virtual reality (VR) [54,55], where the trainee can simulate surgical handling on a virtual patient anatomical model, created in a virtual space. O'Toole and colleagues presented a surgical simulator for the training and assessment of suturing technique, comprised of surgical tools with force feedback, 3D graphical visual display, physics-based computer simulations of the tissues and tools, and software to measure and evaluate the trainee's performance [54]. Although the fidelity of a simulated training environment needs to be greatly improved, the built-in feedback system is projected to assist trainees in gaining and improving upon their surgical skills at a more rapid pace. With further development, VR computer simulation has the potential to become an all-in-one model, featuring not only dexterity training in a high-fidelity environment, but whole procedure training via the use of patient data, with the in-built ability to provide quantified analyses of trainee skill level.

However, in order to perform immersive VR simulation, including the conductance of reliable haptic feedback and reproduction of more real tissue texture, considerable computer modeling is required to simultaneously calculate multiple algorithms [56–58]. In order to optimise VR simulation to a standard suitable for use as a reliable training tool, a picture-perfect reconstruction of surgical reality is required. Without this, the trainee can not correctly interpret the haptic feedback. Further development and time is required, in order to not only achieve these technical goals but also reduce the overall cost.

8. Future perspective

A summary of the characteristics of each training model is listed in Table 5, in which their quality in each respect is judged, in reference to review articles. The data suggests that only VR computer simulation will be able to provide an all-in-one model that features simplicity (accessibility, cost of performance, repeatability), model fidelity (focal, anatomical, physiological), and individual patient simulation as well as quantitative skill feedback with time [38]. However, given that VR computer simulation will take a considerable time to come into practical use as a reliable training tool, each trainee will need to choose from available training models depending on their skill level, preference and type of institution. Training for manual dexterity is necessary for all neurovascular surgeons, whilst learning whole surgical procedures through cadaver or artificial simulator models is also important before proceeding with actual human surgery. To this end, it is thought that a step-up training model is ideal; that is, progressing from synthetic material via chicken vessels to rat or cadaver as a trainee's skill level

Table 5
Summary of characteristics of types of cerebrovascular anastomosis training models

Models	Simplicity			Model fidelity			Patient data
	Cost	Accessibility	Repeatability	Focal	Anatomical	Physiological	
Synthetic materials	+++	+++	+++	–	–	–	–
Animal carcasses	+++	++	++	++	–	–	–
Living animals	++	+	+	+++	–	+++	–
Human cadaver	+	+	+	++	+++	–	–
Artificial simulator	+	+	+	–	+++	–	+++
VR simulator	?	?	?	?	+++	?	+++

VR = virtual reality, +++ = excellent, ++ = good, + = bad, – = unavailable, ? = has not been judged.

improves [47]. Such models may be improved by connecting vessels to a circulation system using human blood. Although each model has advantages and disadvantages (Table 5), combining them in a stepwise fashion will make for an effective training system for each trainee.

Nevertheless, almost all of the aforementioned training models lack a quantitative skill feedback system. One of the keys in boosting training efficiency is a skill feedback system. Load imposed on vessels, appearance of stitches, length of procedure, tool tip trajectory and hand-motion analysis are the main quantitative categories [34,59]. Although there have been several reports of outcome analyses using these categories, they have varied depending on researcher and have generally been judged subjectively [21,34,47,59–61]. A more objective feedback system should be realised at the next stage.

9. Conclusion

Training for microsurgical anastomosis is essential for cerebrovascular surgeons. Although VR computer simulation is expected to produce an all-in-one model, it is likely to be a considerable time until this is achieved. Currently, training for manual dexterity using synthetic materials followed by other biological materials and high fidelity models is the best approach for mastering cerebrovascular anastomosis.

Conflicts of interest/disclosures

The authors declare that they have no financial or other conflicts of interest in relation to this research and its publication.

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