

New Alternative to Animal Models for Surgical Training

Emad Aboud, Carlos Ernesto Suarez, Ossama Al-Mefty and M. Gazi Yasargil

University of Arkansas for Medical Sciences, Department of Neurosurgery, Little Rock, AR, USA

Summary — Laboratory training models are essential for developing and refining surgical skills, especially in microsurgery. A perfect training model is the one that can provide the same situation during surgery, in the same anatomy; the closer to live surgery the model is, the greater the benefit. The lack of an accurate vascular model has sometimes necessitated the use of live models when bleeding, and vascular liquid filling is desired for optional learning. We developed a new model utilising human cadavers that can replace the use of live anaesthetised animals for surgical training. The vessels in a cadaveric specimen were connected to artificial blood reservoirs. The arterial side was connected to a pump to provide pulsating pressure inside the arteries, while the venous side was kept under static pressure that applied to the reservoir. This method provides a condition that simulates live surgery in terms of bleeding, pulsation and liquid filling of the vascular tree. It is an excellent alternative model and can be applied to the whole cadaver or to a particular cadaveric specimen (head, arm, leg) or to an isolated organ. It is distinctive and of a great practical value for training in a wide range of surgical procedures. Utilising this technique could forever eliminate the use of live anaesthetised animals for surgical training. The model and device are patent pending application no. 10/339,053.

Key words: *alternatives, microsurgery, surgical training, vascular surgery.*

Address for correspondence: E. Aboud, National Hospital, Swaida, Syria.
E-mail: aboudemad@yahoo.com or aboud@swaida.com

Introduction

Various kinds of models are available for surgical training (1–9), in addition to cadaveric models. None of them reliably mimic the anatomy and the characteristics of the vascular tree in the human body during live surgery, and in particular, haemorrhage, pulsation and liquid vascular filling. This sometimes necessitates the use of live models. For this reason, live anaesthetised animals have been used occasionally in surgical training (10–20; Figure 1)

We developed a new model in which vessels in a cadaveric specimen were filled with artificial blood (coloured liquid) under a pulsating pressure for arteries and a static pressure for veins. This model simulates that of live surgery in terms of the capability of bleeding, pulsation, vascular liquid filling and softness of the tissue. It allows a trainee to perform any surgical procedure under conditions that resemble live surgery, and it eliminates the need to use animals for laboratory surgical training. This report includes a description of the model and its applications.

Materials and Methods

This model induces pulsation in the arterial tree of a cadaveric specimen by connecting the arteries through their outlet to a coloured liquid reservoir, thus creating a closed system filled with liquid. To

create the pulsation, we used a discarded intra-aortic balloon pump (system 90 Datascope Corp., Fairfield, NJ, USA). The pump was connected to a pressure bag (commonly used). The red liquid reservoir (a plastic serum bag) was connected to the cannulated artery. The reservoir was then placed inside the pressure bag. Changes in the pressure inside the coloured liquid reservoir were transmitted through the connecting tubes to the arteries. The veins were filled with dark red liquid under static pressure.

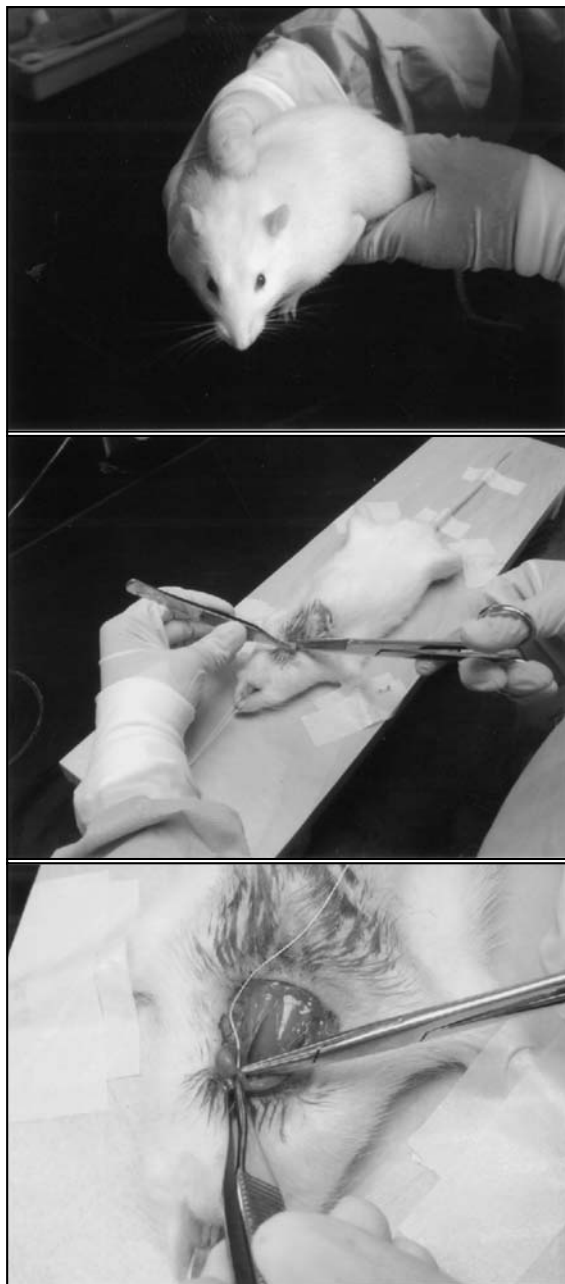
Preparation of cadaveric specimen

Preparation of the cadaveric specimens was similar to the methods described previously (21). As an example, we will describe the preparation of the cadaveric head.

The common carotid arteries, vertebral arteries, and internal jugular veins were exposed by dissecting 1–2cm of each vessel to allow cannulation. Plastic tubes that fit the calibre of each vessel were inserted and tied to the vessel's wall. Precaution was taken to maintain flow to both the internal and external carotid arteries. Two tubes were inserted in the spinal canal to reach the sub-arachnoid spaces.

Tap water was used to irrigate and flush the vessels repeatedly, to remove clots, tissue debris and formalin fixative. Each vessel was irrigated separately until the return fluid was consistently clear. All

Figure 1: Use of live anaesthetised animals in surgical training



other vessels were ligated, and any source of leak in the neck section was clamped or coagulated in order to create a closed system inside the specimen.

The same can be done to prepare the whole cadaver, by using the same vessels that were dissected to inject embalming and fixative materials (the carotid artery and jugular vein in the neck, and the femoral vein and artery in the thigh).

Any other cadaveric specimen can be prepared by cannulating the major vessels of the specimen in the same manner (Figure 2).

Preparation of coloured liquid and operating the system

We used tap water and food colouring to prepare the red and dark red liquids. The containers of coloured liquid were soft and flexible (serum bags worked well). The arteries were injected with red liquid through the carotid and vertebral arteries on one side until flow appeared on the other side. At this point, we closed the opposite carotid and vertebral arteries and continued injecting both ipsilateral arteries simultaneously, applying moderate pressure to open and fill the terminal branches, then closing the ends. The same was done with the jugular veins.

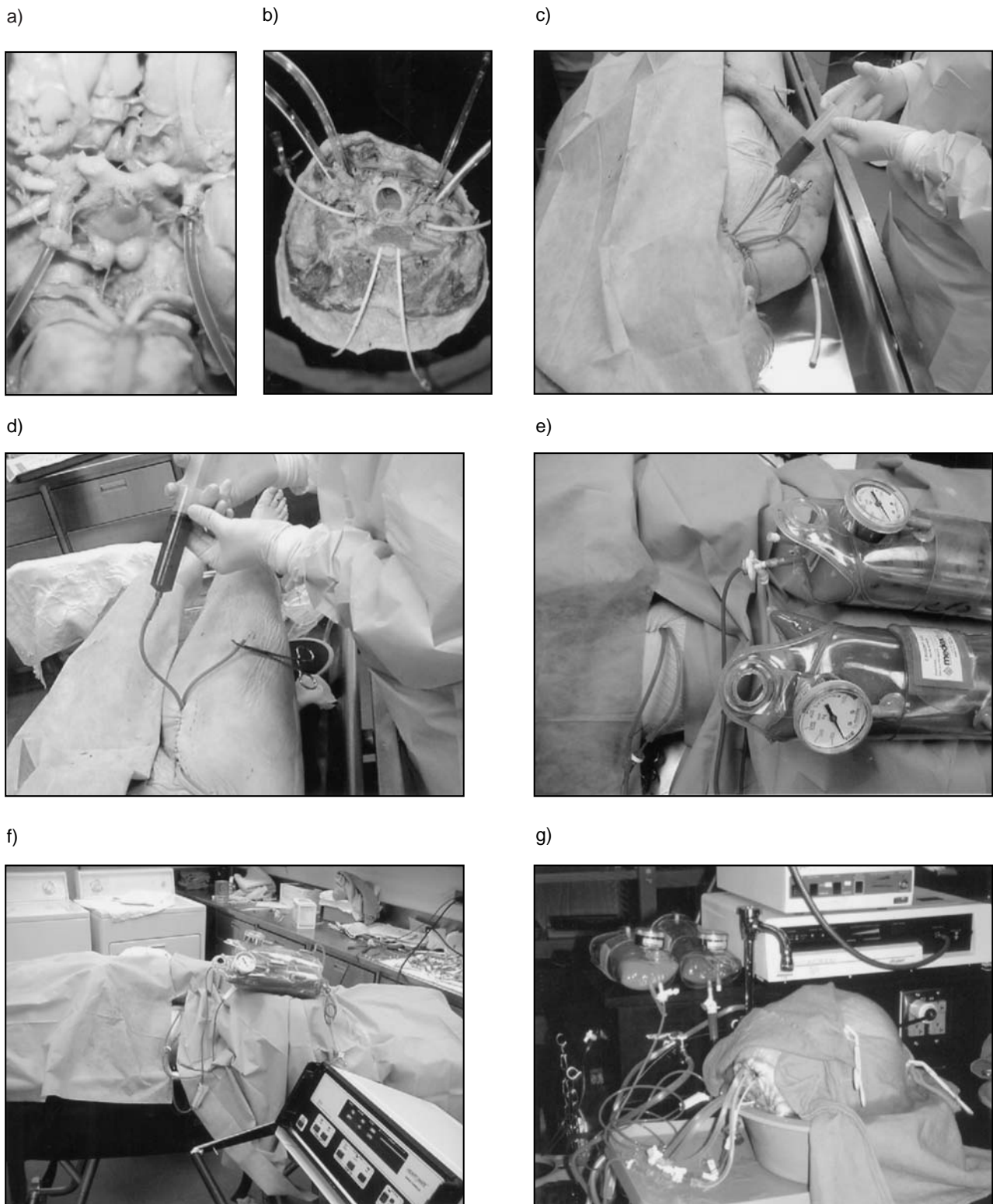
The pressure bag of the red liquid reservoir was then connected to the pump that provides a pulsating pressure that could be transmitted into the red liquid reservoir through the pressure bag. A rate of 60 pulses/minute was selected. (The machine provided a rate of 40–120 pulses/minute). Pressure of up to 150mmHg could be applied through the pressure bag to the source of the red liquid. (We applied a pressure of 80mmHg as a baseline, because the pressure jumped with each pulse in the same way as systolic pressure, due to the pulsating pressure provided by the pump.) The arteries on the other side were kept closed.

The jugular vein on one side was connected to the dark red liquid reservoir, and the contra lateral jugular remained closed. A pressure between 20mmHg and 40mmHg was applied through the pressure bag. The liquid reservoirs were placed at the same level or a few centimetres higher than the specimen to control the pressure and to prevent air embolism in the vessels during dissection. It is possible to create a circulating flow through the circle of Willis by connecting the opposite carotid or vertebral artery through tubes with a one-way valve back into the reservoir. However, there is no advantage of closing the cycle for practising on more distal arteries. Under this pressure and with this kind of cadaveric fixation, there is no real arterial venous circulation. The actual movement of the liquid inside the arteries in our model was back and forth in accordance with the pulse transmitted from the pump, while the liquid inside the veins was static but under pressure. One of the tubes inside the spinal canal was then connected to a serum bag filled with clear liquid, and the flow rate of the liquid was adjusted as desired. The other tube was connected to another liquid container near the specimen to receive the liquid running through the sub-arachnoid space.

Training Procedures and Applications

An unlimited number of training procedures in all surgical specialties can be applied to this method. We

Figure 2: Various cadaveric specimens prepared by cannulating the major vessels and connected to the prototype of the device



a) Cannulating the brain specimen.

b) Cannulating the major vessels in the neck section of the head specimen.

c) and d) Filling the vessels of the whole cadaver with artificial blood.

e), f) and g) The connections between the specimens, blood reservoirs, and the machine.

will thoroughly describe the neurovascular and other neurosurgical procedures that we started with.

To achieve the maximum benefit from the specimen, and to perform all possible procedures before the vessels were damaged, we began with endoscopic and other more superficial procedures and then worked gradually to the depth. All of the training procedures, with the exception of skin incisions and craniotomies (Figure 3a and 3b), were performed under the operating microscope.

Craniotomy

A large scalp flap was made to allow for a variety of approaches. The superficial temporal artery (STA) was preserved for bypass exercises. Bleeding vessels were ligated, coagulated or clamped with Raney clips.

In accordance with the intended procedure, a variety of craniotomies were performed, with

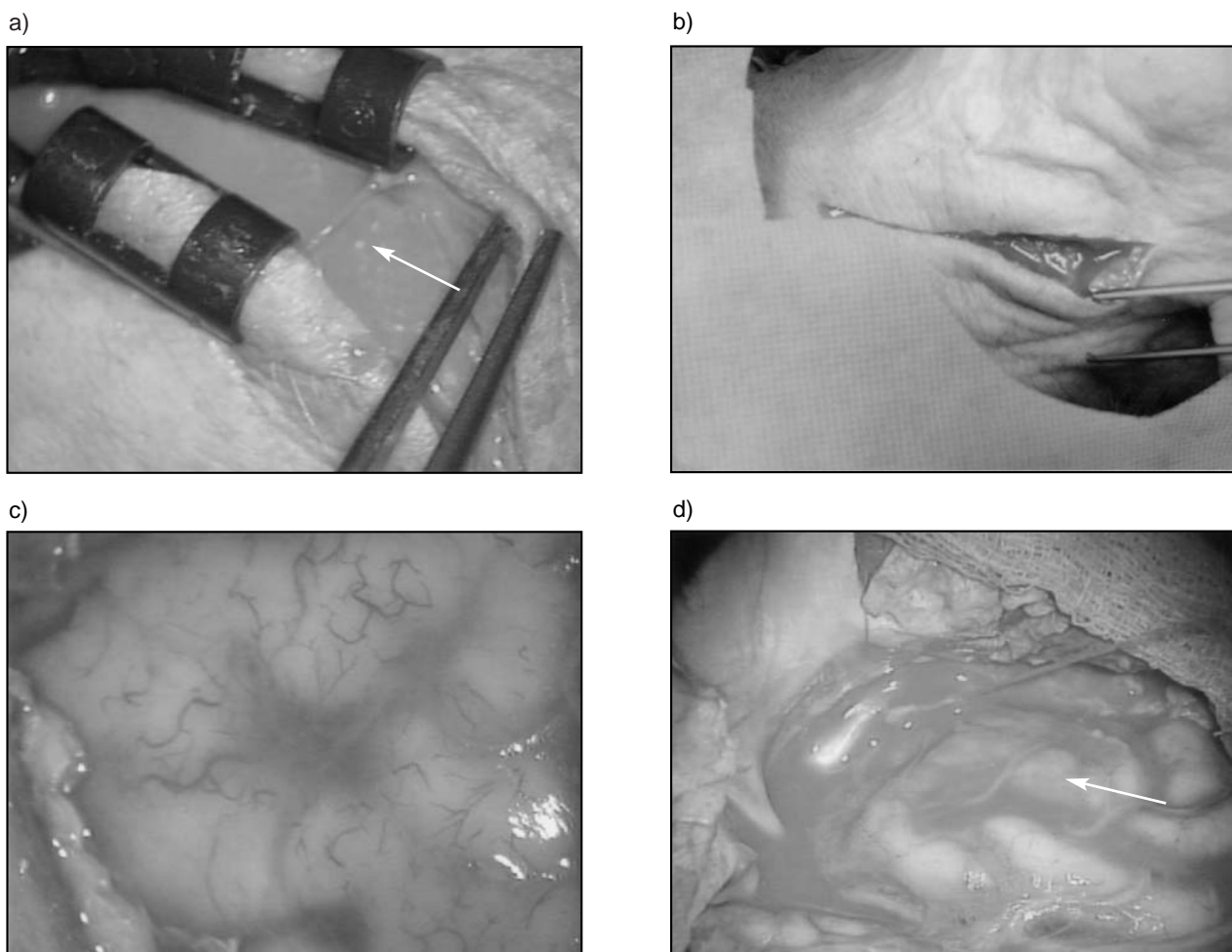
care taken to preserve the underlying dura, which was opened, and leaking vessels were coagulated.

Vascular dissection

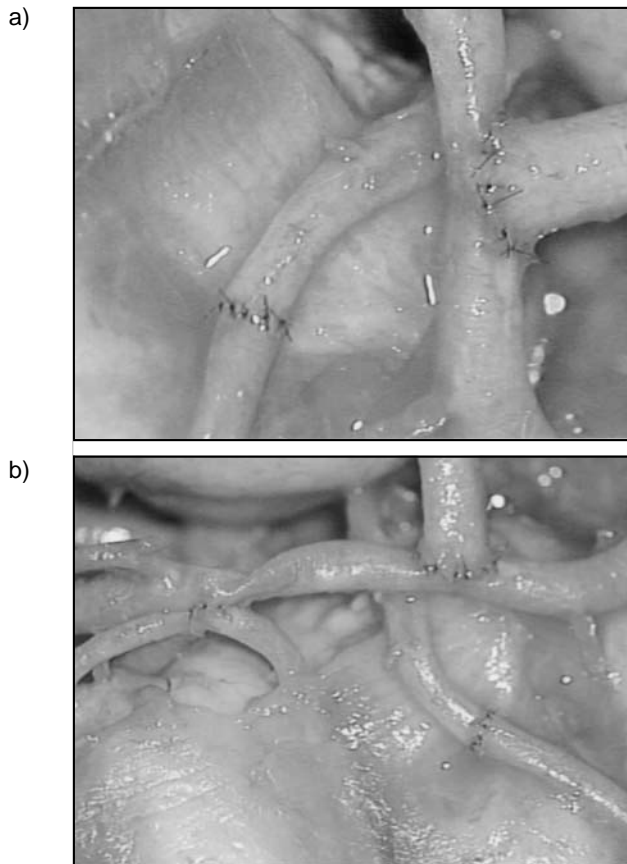
The exposed brain was excitingly life-like, the arteries were red and pulsating and the veins were darker and full (Figure 3c and 3d). As the Sylvian fissure was split, the branches of the middle cerebral artery (MCA) were followed down to the carotid and basal cisterns, thus dissecting the branches of the circle of Willis, and exposing all the neurovascular structures in the skull base. The carotid artery and jugular vein were dissected at the neck and a carotid endarterectomy was performed.

The abdominal cavity was explored; the mesenteric vessels and abdominal viscera appeared as they were in real surgery.

Figure 3: Skin incision and brain surface in the head specimen



*a) and b) Skin incisions in the scalp and the neck; note the bleeding from a sectioned artery (arrow).
c) and d) The life-like brain surface; note the bleeding from a meningeal artery (arrow).*

Figure 4: Vascular repair and anastomosis

a) STA-MCA anastomosis.
 b) Various kinds of vascular anastomosis of MCA branches on the brain surface.

Vascular suturing and anastomosis

A variety of exercises were performed in the head specimen, as well as in the whole cadaver. We started with the establishment of an STA-MCA bypass (end-to-side anastomosis; Figure 4a) and continued with a longitudinal incision repair, a transected artery (end-to-end anastomosis) and a segmental arterial replacement. These were performed on the cortical and deep branches of the MCA artery (Figure 4b). We used various segments of these branches. Each segment was dissected for about 1cm of its length from the overlying arachnoid membrane. Small branches were coagulated and disconnected to free the segment. Two vascular clips were applied on each side of the segment, and arteriotomies were performed according to the kind of repair or anastomosis desired. After suture completion, the temporary clips were released, thus establishing flow under pressure allowing detection of the integrity and patency of the anastomoses.

In the same manner, many kinds of anastomoses and vascular exercises were performed in the extrem-

ities, including drawing blood samples, vein puncture and placement of arterial and central lines.

Cerebral aneurism applications

Artificial aneurisms were created by using a venous graft, such as the Sylvian vein connected by an end to side anastomosis to a major arterial branch. Various shaped aneurisms can be established according to the venous segment and its preparation (Figure 5). Clipping, coagulating and manipulation of aneurisms were practised on the same anatomy and under nearly the same conditions as in real surgery. Aneurismal rupture was simulated by puncturing the aneurism and allowing for crisis management under high pressure bleeding.

Resection of artificial tumours

Gelatin material was injected in different locations of the basal cisterns and intraparenchyma, representing a tumour mass. Resection of these masses from their locations while preserving the neurovascular structures was practised. Skull-base approaches and intraparenchymal resection were practised as well.

Neuroendoscopic procedures

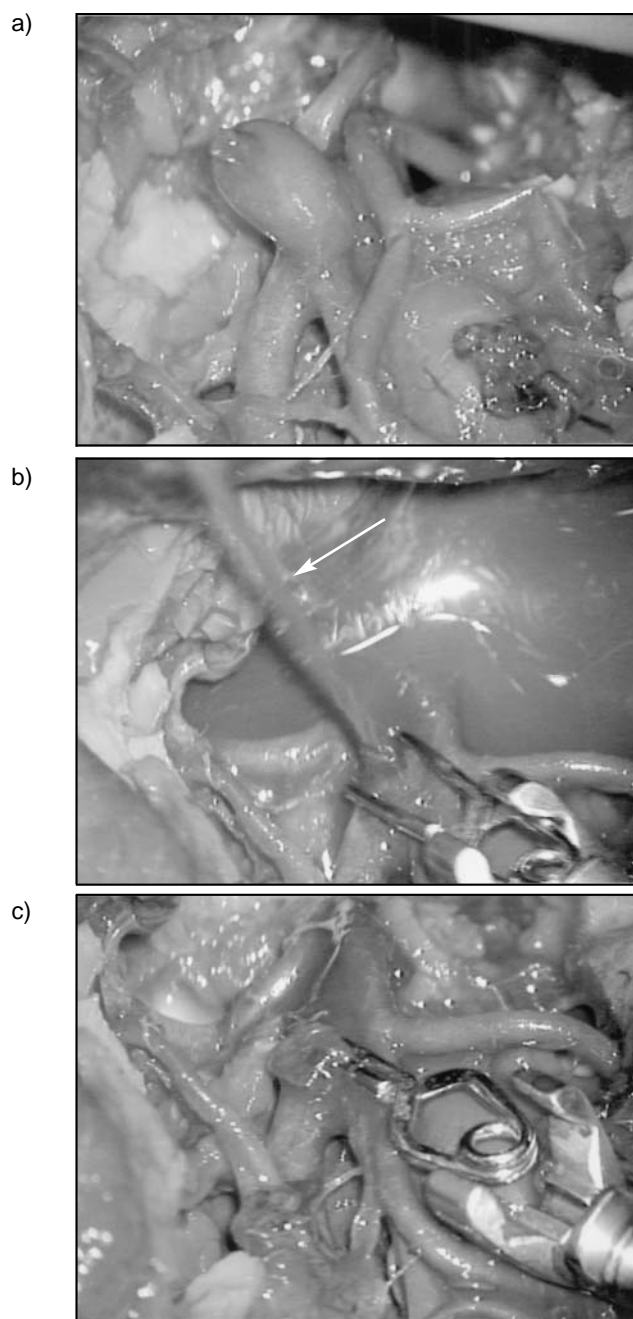
After a frontal burr hole was made, the endoscope sheath was introduced toward the lateral ventricle. The optic was introduced after removing the introducer. The choroid plexus and the septal and thalamic veins were followed to the foramen of Monro. The endoscope then passed the foramen into the third ventricle, and the mamillary bodies and the infundibulum recess were identified. The floor of the third ventricle was perforated in front of the basilar bifurcation in the tuber cinereum area. The basilar trunk and branches, filled and pulsating, were identified in the interpeduncular cistern. Irrigation, management of bleeding, and other manoeuvres were practised.

Results

Our model can increase the capacity of surgical laboratories for training on a variety of surgical approaches, including vascular, endoscopic and even endovascular procedures. This model provided a unique opportunity to practise haemostasis, management of bleeding and the paramount of surgical training under crisis conditions such as ruptured aneurisms, that is not available in any model other than live anaesthetised animals.

We began in our laboratory to use this method in microvascular training for residents and fellows; it

Figure 5: Artificial aneurism application



a) Artificial aneurism created at a major artery.
 b) Bleeding from aneurism rupture; note the bleeding jet (arrow).
 c) Clipping the aneurism.

proved its value as an alternative to animal models in laboratory training.

To complete a training course in microsurgery a trainee needs eight to ten rats to practise all kinds of vascular exercises.

One cadaveric specimen provides an opportunity for numerous training procedures. Trainees can practise on the same specimen for an extended time, as long as

the specimen is preserved, in addition to the advantages of practising on the real human anatomy, while training on anaesthetised animals allows time for only a few procedures, on a strange and different anatomy.

Discussion

Microsurgery in all surgical specialties demands the development of dexterity and skill for basic and fine challenging procedures and techniques. The search for an accurate model for surgical training will not come to an end; it expands with the development of surgical techniques and instrumentation (22–24). Fine manipulation and vascular dissection, suturing and anastomosis were practised using a wide variety of training models, including animals in some instances.

These models were limited to a simple technique, with few numbers of exercises, and they have no relation to the actual anatomy or surgical crisis that may be encountered during live surgery. Live anaesthetised animals may provide a similar situation to live surgery (bleeding, pulsation and soft, oozing tissues), but in a different anatomy, and for only a short period of time before the animal expires. Apart from the cost and other concerns, using even small animals for training is not acceptable, especially when accurate and reliable alternatives are available.

Our model is an accurate alternative model that can represent the human anatomy and can provide the requirements for life-like training (bleeding, pulsation, liquid filling vessels and soft, oozing tissues). Thus, it can replace the use of live animals for this purpose. To our knowledge, a model such as ours has not been developed.

Mechanical pressure pumps have been used to introduce and perfuse embalming fluids via the common carotid or femoral arteries (25, 26). There are no reports of using such machines to induce pulsation and vascular filling in cadavers for training purposes. In studying the role of neurovascular compression in trigeminal neuralgia, Hamlyn, described injection — filling of cadaveric vessels to determine the neurovascular relationships in the posterior fossa (27).

Two shortcomings were found that need additional improvement and can be overcome by other means.

First, the stiffness of the formalin fixed specimens (especially the brain) made exposure and retraction somewhat difficult and, at times, troublesome. To overcome this, we are testing other kinds of cadaveric preparation that provide more relaxed tissue, such as ethylene glycol and other fixation methods, and using fabric softener materials (28) that make the tissue soft and retractable.

Second, coagulation of the cadaveric vessels without vascular tone, and the blood coagulation mechanism, made haemostasis by coagulation a more tedious matter (that might be a favourable flaw for practising). Further improvements of the nature and viscosity of the current liquid might resolve this problem.

Conclusion

This model adds a new dimension to microsurgical training and increases the usefulness of training courses by enabling the practice of many surgical procedures and techniques simulating real live surgery that is richer and superior to using plain cadaveric specimens or anaesthetised animals.

Adopting this technique could forever eliminate the use of live animals in both human and veterinary surgical training.

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