New laboratory model for neurosurgical training that simulates live surgery

EMAD ABoud, M.D., OSSAMA AL-MEtY, M.D., AND M. GAZI YAŞARGIL, M.D.

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

Object. Laboratory training models are essential for developing and refining surgical skills, especially for microsurgery. The closer to live surgery the model is, the greater the benefit. In this paper the authors introduce a cadaver model with unique characteristics: dynamic filling of the cerebral vasculature with colored liquid and clear fluid filling of the arachnoid cisterns. This model is distinctive and has great practical value for training in a wide range of surgical procedures.

Methods. Cadaveric heads were prepared for surgical procedures in the following manner: the carotid arteries (CAs) and vertebral arteries (VAs) in the neck were cannulated, as were the internal jugular veins (JVs) on both sides. Two tubes were introduced into the spinal canal and each one was advanced into one of the cerebellopontine angle cisterns. A CA, VA, or both were then connected to a reservoir containing light red fluid and a pressure of 80 to 120 mm Hg and a pulse rate of 60 beats/minute were established using a pump. The JV on the side currently being dissected was connected to a reservoir containing dark red fluid and kept at a pressure between 20 and 40 mm Hg. The remaining vessels were clamped in the neck. The cisternal tubes were connected to a reservoir of clear fluid that was regulated by an adjustable flow. Nine trainees have tested this model on eight specimens by practicing a variety of surgical procedures and maneuvers, including craniotomies; hemostasis; cisternal and vascular dissection; vascular anastomosis and repair; establishment of arterial bypasses; aneurysm creation, dissection, and clipping; management of an aneurysm rupture; intraparenchymal resection such as amygdalolimbicectomy; ventricular endoscopy and third ventriculostomy; cavernous sinus and skull base approaches; and resection of artificial tumors in the basal cisterns.

Conclusions. This model mimics the normal human anatomy and dynamic vascular filling found in real surgery and presents it from the training perspective, allowing a wide range of skill development and repeated practice. It provides an alternative model to laboratory animals. It is inexpensive and readily available, and has great value for the acquisition and refinement of surgical skills that are not only specific to neurosurgery, but are applicable to other surgical disciplines.

Key Words • cadaver dissection • surgical training • training model • cerebral vasculature • neurosurgery

Abbreviations used in this paper: BA = basilar artery; CA = carotid artery; JV = jugular vein; MCA = middle cerebral artery; STA = superficial temporal artery; VA = vertebral artery.

Materials and Methods

With this model pulsation is induced in the arterial tree of a cadaveric head by connecting the arteries through their outlet in the neck to a reservoir of colored fluid and creating a closed system filled with fluid. To create the pulsation, we used a discarded intraaortic balloon pump (System 90;Datascope Corp., Fairfield, NJ). The pump was connected to a pressure bag that is commonly used. The reservoir (a plastic serum bag) filled with light red fluid was connected to the cannulated artery. The reservoir was then placed inside the pressure bag. Changes in pressure inside the reservoir of colored fluid were transmitted through the connecting tubes to the arteries. The veins of the cadaveric head were filled with dark red fluid under static pressure.

Preparation of Cadaveric Heads

Preparation of the cadaveric specimens was similar to methods described previously. The common CAs, VAs, and internal JVs were exposed by dissecting each vessel 1 to 2 cm to allow cannulation. Plastic tubes selected to fit the caliber of each vessel were in-
serted and tied to the vessels’ walls. Precautions were taken to maintain flow to both the internal and external CAs. In addition, one 8- to 10-gauge tube was inserted intradurally into each side of the spinal canal and advanced to reach the intracranial subarachnoid space; after this the canal was plugged with bone wax (Fig. 1).

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. The subarachnoid space was washed using the tubes placed in the spinal canal. Any leaks from arteries and veins on the sectioned surface of the neck were sealed either by ligation or coagulation.

Preparation of Colored Fluid and Operation of the System

We used tap water and food coloring to prepare the light red and dark red fluids. The containers of colored fluid were soft and flexible (we found that serum bags worked well). The arteries were injected with light red fluid through the CAs and VAs on one side until flow appeared on the other side. At this point, we closed the opposite CA and VA, and continued injecting both ipsilateral arteries simultaneously, applying moderate pressure to open and fill the terminal branches and then closing the ends. The same procedure was performed with the JVs.

The pressure bag of the light red fluid reservoir was then connected to a pump. This pump provides a pulsating pressure that can be transmitted into the red fluid reservoir through the pressure bag. A rate of 60 pulses per minute was selected; the machine provided a rate of 40 to 120 pulses/minute. Pressures up to 150 mm Hg can be applied through the pressure bag to the source of the red fluid. For our purposes, we applied a pressure of 80 mm Hg 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 of the head were kept closed.

The JV on one side was connected to the reservoir containing dark red fluid and the contralateral JV remained closed. A pressure ranging from 20 to 40 mm Hg was applied through the pressure bag. The fluid reservoirs were placed at the same level or a few centimeters higher than the specimen to control pressure and prevent air embolisms in the vessels during dissection (Fig. 2). It is possible to create circulating flow through the circle of Willis by connecting the opposite CA or VA through a tube with a one-way valve back into the reservoir. For practicing on more distal arteries, however, there was no advantage of closing the cycle. Under this pressure and using this kind of cadaveric fixation, there was no real arterial–venous circulation. The actual movement of fluid inside the arteries in our model shifted back and forth according to the pulse transmitted from the pump, whereas the fluid inside the veins remained static, albeit under pressure. One of the tubes inside the spinal canal was then connected to a serum bag filled with clear fluid, which was located at a higher level than the specimen. The fluid advanced through the tubes to the subarachnoid space under gravity and the flow rate of the fluid was adjusted as desired. The other tube was connected to another fluid container near the specimen. This is designed to receive the fluid running through the subarachnoid space or is kept closed when suction is used during the training procedures; it can also be used alternatively with the first tube. Having clear fluid running in and out of the subarachnoid space provides another advantage by keeping the cisterns clean and preventing staining due to deposits of the colored materials.

Results

Training Procedures and Applications

To achieve the maximum benefit from the specimen and perform all possible procedures before the vessels were damaged, we started with endoscopic techniques and other procedures that could be performed on the surface of the cadaveric head and worked gradually to its depth. All training procedures, with the exception of craniotomies, were performed with the aid of an operating microscope.

Craniotomy. A large scalp flap was made to allow a variety of approaches. The STA was preserved for practicing an STA–MCA bypass. Bleeding vessels were ligated, co-
agulated, or clamped using Raney clips. According to the intended procedure, a variety of craniotomies were performed, with care taken to preserve the underlying dura mater. The edges of the bone were waxed to prevent a fluid leak. The dura mater was opened and leaking vessels were coagulated (Fig. 3).

Cisternal and Vascular Dissection. The exposed brain was extremely lifelike (Fig. 4); the arteries were light red and pulsating, the veins were dark red and filled, and a clear fluid simulated the release of cerebrospinal fluid when the arachnoid was opened. We split the sylvian fissure and followed the branches of the MCA down to the carotid and basal cisterns, dissecting the branches of the circle of Willis and exposing all neurovascular structures in the skull base.

Vascular Suturing and Anastomosis. A variety of exercises were performed, starting with the establishment of an STA–MCA bypass (end-to-side anastomosis) and including repair of a longitudinal incision or a partial arterial defect and a transected artery (end-to-end anastomosis), as well as segmental arterial replacement. These procedures were performed on the cortical branches of the MCA and the M1 and M2 branches deep within the fissure. We used various segments of these branches. Each segment was dissected for approximately 1 cm of its length from the overlying arachnoid membrane. Small branches were coagulated and disconnected to free the segment. Two vascular clips were applied on both sides of the segment and arteriotomies were performed according to the kind of repair or anastomosis desired. After suture completion, the temporary clips were released, establishing flow under pressure and allowing detection of the integrity and patency of the anastomoses (Fig. 5). Some specimens had a remnant of thrombus inside the branches of the MCA; this provided the opportunity to perform a thrombectomy and resuture the vessel (Fig. 6).

Aneurysm Applications. Artificial aneurysms can be created in several ways. Selecting one of the better methods, we created an artificial aneurysm by using a resected segment of the sylvian vein. The segment was sutured by end-to-side anastomosis to a major arterial branch and the free end of the segment was ligated to form the sac. Various shaped aneurysms can be created according to the characteristics of the venous segment and its preparation. Clipping, coagulation, and manipulation of aneurysms were practiced on the same anatomy and under nearly the same conditions found during real surgery; aneurysm rupture was created by puncturing the aneurysm, which provided the trainee with the experience of crisis management under high-pressure bleeding (Fig. 7).
Resection of Artificial Tumors and Other Procedures. Gelatinous material was injected into different locations of the basal cisterns and within the parenchyma to represent a tumor mass so that the trainee could practice resection of these masses while preserving neurovascular structures (Fig. 8). Skull base approaches, intraparenchymal resections, and other procedures that we usually practice in cadavers prepared using traditional methods were practiced as well.

Endoscopic Procedures. After a frontal burr hole had been made, the sheath of the endoscope was introduced toward the lateral ventricle. The optic apparatus was introduced after the introducer had been pulled out, and the choroid plexus and the septal and thalamic veins led the way to the foramen of Monro. The endoscope passed the foramen into the third ventricle and the mammillary bodies and the infundibular recess were identified. The floor of the third ventricle was perforated in front of the BA bifurcation in the area of the tuber cinereum. The BA trunk and branches, which were filled and pulsating, were identified in the interpeduncular cistern. Practicing irrigation and clearing of liquid inside the ventricles was achieved, as were observing the pul-

Fig. 7. Management of aneurysm bleeding. A: Artificial aneurysm located on the MCA bifurcation. B: Bleeding jet from the punctured aneurysm (arrow). C: Temporary clipping of the MCA. D: Clipping of the aneurysm neck.
Utilization of Both Hemispheres

All the aforementioned procedures were then performed on the other side of the cadaveric head after the MCA on the first side had been closed and all ruptured vessels had been coagulated or clipped. The CA and the JV on the second side were connected to the colored fluid reservoirs. (Changing connections from side to side between the VA and the JV and the fluid reservoirs had no impact.) The same procedures were then performed on the second side in addition to interhemispheric approaches.

Posterior Circulation

When all possible training procedures on the anterior circulation had been completed, the CA was disconnected and the posterior communicating arteries were clipped on both sides proximal to the posterior cerebral arteries. The VA from one or both sides was connected to the reservoir filled with light red fluid and one of the JVs was connected to the source of the dark red fluid. Dissection of the posterior fossa and posterior circulation, in addition to previously mentioned procedures, were then performed through the occipital and suboccipital approaches.

Whole-Brain Application

We also applied this method in a whole-brain specimen obtained at autopsy. In this case both CAs were cannulated, allowing a variety of vascular exercises on the major branches (Fig. 9).

Discussion

As a surgical specialty, neurosurgery requires the development of dexterity and skills for basic and challenging procedures and techniques. In delicate organs such as the central nervous system, the surgeon’s individual skills play a crucial role in determining patient outcome. Hence, the emphasis has been placed on laboratory training, preparing surgical trainees for the operating room experience. The fine manipulation and dissection of cerebral vessels with anastomosis usually have been practiced on animals. Unfortunately, these procedures are limited to a simple technique and have no relation to the actual anatomy or to surgical crises that are encountered by the trainee during live surgery. A critical part of this training is mastering the anatomy. Hence, fine publications, methods, and courses are richly introduced and widely available.

To improve the illustrative value of cadaver dissection, colored materials are injected into the vessels of cadavers to identify arteries and veins for anatomical studies. Fluorescein and radiopaque substances, silicone, gelatin, latex, acrylic, or tinted polyester resin have been used for this purpose. Mechanical pressure pumps have been used to introduce and perfuse embalming fluids via the common CAs or femoral arteries. Nevertheless, there have been 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 neurovascular relationships within the posterior fossa.

To our knowledge, a model such as ours has not previously been developed. This model can increase the capacity of neurosurgical laboratories to train for a variety of surgical approaches, including skull base, neurovascular, endoscopic, and even endovascular procedures. The presence of clear fluid in the subarachnoid spaces, the pulsation, and the vascular filling give greater realism to these training procedures. This model provides the trainee with a unique...
opportunity to practice hemostasis, management of bleeding, and the paramount tasks of surgical training under crisis conditions, such as the presence of a ruptured aneurysm, which are not available using any alternative model. Similar opportunities for training can be offered to other surgical disciplines because the system can be used on other organs or on whole cadavers.

One cadaveric head provides an opportunity for numerous training procedures. Trainees can practice on the same specimen for a long time, as long as the specimen is preserved. Training on anesthetized animals allows only the time for a few procedures.

Training procedures are not the only application of this method; we can study the hydrodynamic features of the cerebrovascular tree; the blood supply of anatomical regions, collateral areas, and vascular alignments; and the actual relationships between neurovascular structures inside the skull.

Two shortcomings exist that require additional improvements and can be overcome using other means. First, although most of the aforementioned procedures and exercises have been performed in stiff formalin-fixed brains, we found that the stiffness of these brains made exposure and retraction somewhat difficult and at times troublesome. To overcome this we used fresh, partially embalmed cadavers that provided more relaxed and retractable brains; however, these specimens do not last long. Other preparations that produce a softer brain can be used, such as ethylene glycol and other fixation methods or application of fabric softener materials, which make the brain soft and retractable. The second shortcoming is found in coagulation of cadaveric vessels that have no vascular tone in the absence of a blood coagulation factor; these conditions made hemostasis by coagulation more tedious than it is in real surgery (although that might be a favorable flaw for practicing skills). Smaller vessels and points of intraparenchymal oozing were coagulated more easily than big vessels, and the smaller the diameter of the vessel, the better the conditions for coagulation. Further improvements in the nature and viscosity of the fluid we are currently using might resolve this problem.

Conclusions

This model adds a new dimension to neurosurgical training and increases the usefulness of such courses by enabling the trainee to practice many surgical procedures and techniques under conditions simulating live surgery. This model provides a richer and superior training experience than that attained using plain cadaveric specimens or anesthetized animals.

Acknowledgments

The authors acknowledge the assistance of Mrs. Dianne Yaşargil and Mrs. Amy Keeland in the preparation of this study.

References


Manuscript received April 1, 2002. Accepted in final form August 7, 2002. Address reprint requests to: Ossama Al-Mefty, M.D., Department of Neurosurgery, University of Arkansas for Medical Sciences, 4301 West Markham, Slot 507, Little Rock, Arkansas 72205. email: keelandamyte@uams.edu.