16 Neurosurgery Teaching Techniques and Neurosurgical Simulation

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16.1 INTRODUCTION

What is the process through which a medical student becomes a neurosurgeon? How do we teach the skills necessary for success? What role does a resident play in his or her own educational process? Before consideration of neurosurgical simulators, we should first reflect on these questions and understand the processes by which neurosurgeons are currently trained. Then we can consider ways in which the potential benefits of simulation and other new teaching techniques may contribute to the process.

The current process clearly has many limitations because of the long hours and number of years required for training and defining the need for additional manpower. Simple questions remain unanswered, such as whether neurosurgery training should
be closed-ended (a fixed number of years as is currently the practice in the United States) or open-ended (until a job opens, possibly after many years of training, as is commonplace in other areas of the world).

16.2 CURRENT NEUROSURGICAL TRAINING

16.2.1 Apprentices to Practitioners

Traditionally, neurosurgical residency has been an apprenticeship process in which residents spend several years with experienced neurosurgeons and participate in all aspects of the profession. The environment for this apprenticeship is audited for sufficient operative cases and approximate measures of the adequacy of the learning experience through conferences and exam certifications. Residents learn operative techniques, surgical anatomy, clinical management, and the subtleties of interactions with patients and families. As with any apprenticeship, the resident gradually assumes more responsibility and autonomy.

Training is regularly supplemented with lectures, small-group learning sessions, and self-study. In addition, a significant portion of training occurs during interactions of residents. “Senior” residents help in the training of “junior” residents. Ultimately, neurosurgical residents are exposed to the information and clinical experience that will prepare them to leave training for the next phase of their practices. The goal is to produce high quality, independently functioning neurosurgeons, who are competent, adhere to high standards of professional conduct and patient care, and serve as assets to their communities.

A critical part of the training process is evaluation of a resident’s performance throughout the training period. Advancement is often dependent on completion of various milestones judged internally at the training institution or by national boards. Emphasis is now placed on evaluating residents from all specialties on six core competencies involving knowledge, judgment, behavior, and technical skill:

1. Patient care
2. Medical knowledge
3. Interpersonal and communication skills
4. Professionalism
5. Problem-based learning
6. Systems-based learning

The process of acquiring factual knowledge and clinical judgment occurs in several ways. The most direct method is a program of self-directed study via textbooks, journal articles, and Medline searches, but the method has a limited role for teaching clinical judgment. Another way of gaining factual knowledge and judgment is through apprentice relationships with attending physicians and senior residents during patient rounds and small group discussions, or from lectures and grand rounds. These types of learning programs typically include consideration of clinical examples, review of factual knowledge, and Socratian-type interactions between...
residents and mentors. The learning processes have recently been augmented through the advent of evidence-based medicine (see Chapter 15). The advantage of this type of learning is that significant information can be efficiently imparted by the mentor. However, the process relies to some extent on the mentor’s experience and willingness to teach.

A potential role of neurosurgical simulation is its use in the form of a clinical database that can be used by students to improve their factual knowledge and, to an extent, their judgment and clinical decision making, by taking advantage of a wider array of cases than may be present at one institution or during one training period.2,3 Apprenchices also tend to retain local practices and knowledge that may be sometimes parochial and limited by their mentors’ views of the world. Such local preferences may then be treated as dogma, only to be perpetuated later as neurosurgical myth. Such biases can be retained for many years and may be difficult to recognize and outgrow.

### 16.2.2 Judgment in Neurosurgery

Is our current system of neurosurgery training only a Halstedian, apprenticeship process?3 Neurosurgery clearly has two aspects: judgment — how to decide to whom to suggest a surgical procedure and on what rationale — and technical — how to perform a procedure with maximal efficacy and least risk. While considerable emphasis is placed on the technical aspects and learning, less stress focuses on the judgment side, which is the more critical in terms of subsequent liability and practice enjoyment.

Typically, judgment is taught Socratically, by questioning and answering, by building an internal database containing patient symptoms, common syndromes and their treatments, and knowledge about procedures, outcomes, risks, and recovery times. Judgment is usually considered as a case-by-case set of rules that can be internalized, but which are subject to basic hypotheses, principles, and background knowledge. Development of judgment requires time and experience. Honing and refinement take into account past successes and failures. For example, selecting patients appropriately for surgical approaches often involves taking into account past cases from personal experience along with outcomes cited in the evidence-based literature.

### 16.2.3 Technical Aspects of Neurosurgery Teaching

The process of learning neurosurgical technique includes mastery of complex three-dimensional anatomy, visuospatial perception, and motor skills. Intraoperative training is the most direct method for developing these skills. It constitutes the gold standard for learning neurosurgical technique and ultimately forms the foundation of a neurosurgeon’s career. Typically performed through an apprentice relationship with senior surgeons, it reflects the model of surgical training pioneered by Halsted.

Anatomy and technique are learned through observation of a senior surgeon and directly in a supervised setting. The dual-headed microscope has greatly facilitated this type of learning. Intraoperative training, however, has several important limita-
The environment can be relatively limited by time and tension because of potential risks or bad outcomes and may not foster education as the primary goal. Additionally, anatomic exposure is necessarily limited to what is clinically warranted, and usually this is minimized to improve recovery time, hampering visualization in many situations. Ultimately, patient care must always take priority over education. In this regard, virtual reality simulators may help residents advance sooner by demonstrating more complete dissections and underlying anatomy.

In contrast, technical aspects can usually be taught by direct supervision or by animal approaches such as implementing microvascular anastamoses in small rodents. Technical expertise is a combination of practice, supervision providing guidance, and the repetitive use of the hands as needed for motor learning. The technical side is currently handled by direct observation and apprenticeship, with progressive responsibility based on certain steps or levels. The levels can be indexed according to degree of difficulty (i.e., carpal tunnel, disc, and shunt procedures preceding craniotomies). Milestones that must be achieved before residents progress to the next level are documented.

One training tool is cadaveric dissection that provides residents the potential to improve anatomic understanding, visuospatial perception, and motor skills. Cadaveric dissections are interactive, three-dimensional, and relatively transferable to the operating room setting. However, dissection also has important limitations including significant costs (preparation, facilities, instructors, and equipment), limited availability of specimens, and the substantial differences between living and cadaveric tissues. Finally cadaveric dissection involves a substantial time commitment and is not amenable to repeated rehearsal of a specific procedure.

Animal dissection provides opportunities to improve visuospatial and motor skills, but the technique has both practical and ethical limitations and the anatomic differences are usually significant. Thus, current training involves a large amount of direct intraoperative assisting to allow direct visualization of human anatomy and exposure and small (but key) cadaveric and small animal dissection experience to augment the clinical experience gained over many years.

### 16.2.4 Training Objectives

The goal of training is to produce fully trained academic neurosurgeons who are clinically competent and have excellent technical skill, superb judgment, and thorough knowledge of related disciplines, including basic neuroscience, neurology, neuropathology, and neuroradiology. Technical competence is achieved through “gradual delegation of earned responsibility for investigative and operative care to penultimate levels.” The development of competence in clinical neurosurgery requires a trainee to:

1. Master the principles of surgery
2. Become familiar with the basic science and diseases of the nervous system
3. Develop the necessary technical skills to perform neurosurgical procedures
4. Learn to relate and work effectively with colleagues in medicine and surgery and other health care professionals and ensure the development
of a keen sense of responsibility and compassion toward patients and their families

5. Understand the impacts of neurosurgery on society including medical ethics, health care economics, law, prevention of disease, and promotion of health

6. Develop an understanding of clinical and basic research techniques including biostatistics and epidemiology

Residents must assume graduated responsibility throughout the course of their residencies in terms of background knowledge, pre- and postoperative management, operative experience and independence in decision making. However, supervision is critical to a training program, and feedback from more experienced individuals is essential to education along with a constant and sincere effort to learn on the part of the resident.

Patient care is the core background to neurosurgical education and thus intimate knowledge of patients forms the basis for informed decision making and increased participation by residents in patient care decisions and management. The objectives for technical competence build upon progressive training experience in neurosurgical procedures, usually in an apprenticeship mode under direct supervision.

16.3 ARE THERE TRAINING DEFICIENCIES?

The current fixed length residency program is relatively short, compared to the large number of judgment skills, procedures, and care issues that must be adequately taught. It does not account for the varying learning rates of different physicians. For that reason, some flexibility in training length may be important to accommodate and overcome such differences. The current 80-hour work week limitation makes it difficult to take occasional night calls and allow sufficient patient follow-up to adequately assess a resident’s judgment. These limitations are compounded by insufficient exposure to and understanding of less common cases because residents commonly handle more common situations.

The skills routinely taught in most residency programs are primarily aimed at a high quality clinical practice situations. They are not necessarily directed toward academic investigations in the fields of basic neuroscience, translational neuroscience, or clinical neuroscience. For many years, the minimum requirement for the adequate pursuit of quality basic neuroscience has been at least 3 to 5 years of experience beyond residency, at the graduate student (i.e., M.D.–Ph.D. combined degree), postdoctoral, or mentored faculty level. This additional time is critical for enabling clinician investigators to become sufficiently qualified to compete for external funding from federal (National Institutes of Health, Department of Veterans’ Affairs, Department of Defense, etc.) or foundation sources.

Unless a clinician investigator is competitive in obtaining funding, it is unlikely that research of sufficiently high quality will continue to make valuable contributions to neurosurgery and the wider field of neuroscience. Developing and maintaining adequate clinical credentials and sufficient research experience to be truly competitive are difficult challenges at both the resident trainee and faculty levels. These
abilities are under-emphasized. The difficulties are compounded by the additional requirements for teaching and mentoring, as well as family commitments and obligations (Figure 16.1). Ethically, family commitments cannot be handled by a substitute person and have a much higher priority than any of the other demands. Anyone can be replaced professionally unless, of course, his or her ego cannot tolerate replacement.

To meet translational and clinical neuroscience objectives, a master’s in public health and epidemiology (M.P.H.) may provide a suitable path. This initial degree provides some training in clinical investigation and trial design and can provide a base upon which to build further training. Additional career pathways for clinical neuroscience investigation should include training in epidemiology and statistics as well as in clinical trial design and principles of translating neuroscience concepts into clinical utility. These training issues have been discussed in terms of capacity for translational research within academic medical centers, and the projected need for manpower to perform critical studies in the future (see Chapter 1).

Since the general public is somewhat suspicious of the involvement of residents in procedures and “ghost surgeries (where a resident performs a procedure without supervision),” it is critical that adequate supervision be present at all times and that optimal use of technical training outside the operative suite be encouraged before

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residents are allowed to perform procedures on humans. Clearly, current training could be expanded to become less of an apprenticeship and more of a truly educational experience by optimizing knowledge-based and judgment-based approaches in every situation possible instead of viewing training as a rote technical exercise. Surgical simulation and practice judgment may go a long way toward supplementing traditional, wholly patient-based approaches.

16.4 HOW DO WE IMPROVE OUR TRAINING CAPABILITIES?

16.4.1 JUDGMENT TRAINING DEVELOPMENTS

Web approaches for developing data to support judgments made in the course of considering procedures are currently in development. These approaches enable practitioners to learn and test the processes of making judgments including making rational decisions, basing decisions on evidence in the literature, and methods of presenting the decisions to patients. As discussed in Chapter 15, fallacies are present at all levels of evidence, particularly in small specialties such as neurosurgery, in which randomized controlled trials are rarely performed due to small patient populations. In cases like neurosurgery where it is not always possible to obtain high level evidence because of small patient populations, the ability to infer information from the existing literature is critical for optimal decision making. Development of improved patient encounter simulations may also help in understanding how differently patients may value a surgical procedure; for some patients, the negative aspects of surgery may outweigh any possible benefits.

16.4.2 TECHNICAL TRAINING ADVANCES

Technical training is currently limited by the availability of suitable patient encounters and the teaching skills of mentors in teaching settings. While cadaver surgical approaches are common methods of practicing skills and can be very useful, the tissue characteristics (for example, brain deformation properties) of a cadaver differ from those of an intact patient in vivo. There is considerable interest in surgical simulation, particularly in virtual reality immersion settings similar to simulation devices used to train aviators. This type of simulated environment, usually involving virtual reality goggles and realistic touch and tactile feedback and various types of instrumentation, allows simulation of manipulation of tissues in vivo.

These techniques rely on sophisticated three-dimensional renderings and models of tissue deformations to mimic realistically the properties of the brain, skull, spinal cord, and nerves. While such approaches are very demanding computationally, limited views have been incorporated into endoscope viewers and are used during intraventricular endoscopy procedures in which video simulations can be combined with appropriate tactile feedback.

16.4.3 SIMULATION TECHNIQUES

Simulation may be broadly defined as the use of technology to recreate key elements of an interactive experience, usually accomplished through a computer interface and
routinely including visual representations and some degree of interactive control. Simulation can include any of several components of an experience including visual, auditory, tactile, or even conceptual. Depending on the skills to be trained, a simulator may include one or more of these elements. In addition, the user’s experience will be influenced by background knowledge. Theoretically, an ideal simulator is one in which the user is unable to distinguish between the simulation and the actual experience.\textsuperscript{2,4,8}

Current real-world limitations preclude the complexity this would necessitate, but our ability to suspend disbelief allows us to develop effective simulators despite their not being mistaken for reality. While an ideal simulator would potentially recreate every aspect of an experience and be identical to reality, this is neither necessary nor especially important. For example, a simulator of neurosurgical anatomy can still have significant value even if it lacks a tactile component. Certainly the potential costs and implementation efforts required to produce a “complete” simulator would make the device prohibitive and necessitate compromise.

It is not necessary or even important for a simulation system to “fool” the user. By accepting this principle, we can greatly reduce the potential hurdles to developing an effective, accessible simulator. It is essential to recognize that prohibitive costs and limited access can effectively make the world’s best simulators valueless. Several high-end simulators have followed this path. The opportunity to provide inexpensive, readily available simulation is clearly the promise of the personal computer. In fact, the best simulators may be inexpensive and work on standard personal computers. Such devices will actually be used and can accomplish some or all of the potential goals of simulation.

The potential benefits of simulation are most significant if the experience simulated is uncommon, poses high risks, or demands extensive rehearsal. Flight simulators have been tremendously successful because they allow pilots to gain valuable experience without risk to themselves, their passengers, innocent bystanders, and expensive aircraft. In addition to frequent rehearsal of fundamental techniques, flight simulators allow pilots to experience unusual and dangerous situations in completely controlled environments. Similarly, surgical simulators offer several potential advantages including the ability to frequently rehearse the steps of a surgical procedure, familiarity with normal and unusual anatomies, and the potential for improved reactions to adverse events. These advantages are useful for educating residents, maintaining certifications, and disseminating novel or very complex techniques. From the perspectives of training and public perception, the potential advantages of simulation are improved surgical skill, minimization of surgical errors, and alternatives to learning on patients.\textsuperscript{2,3,4}

16.4.4 SURGICAL NEUROANATOMY REPRESENTATION

The potential for simulators to augment visuospatial and motor skills is significant. The most common simulators are based on graphical representations of surgical neuroanatomy. They are typically animation-based or rely on photorealistic images to recreate the visual experiences of surgery. The more advanced simulators allow tissues to be deformed in a physically realistic manner. This involves substantially
increased computational requirements and general assumptions about tissue characteristics.

A popular technique for accomplishing this type of deformation is the use of mass-and-spring lattices to model surfaces of structures. A surface is assumed to be composed of a series of masses connected to each other by springs. Mathematical calculations can then be used to determine the degree of deformation associated with a particular force. This technique is less useful when attempting to model cut surfaces. For this reason, the use of finite element analysis has become popular. While providing more physically realistic tissue behavior, the computational requirements become substantially higher.

The use of haptics in neurosurgical simulators lends an additional degree of realism and training potential. Haptics is defined as the use of tactile feedback in an interactive experience. Examples of haptics include force feedback joysticks, exoskeletons, and semiconstrained robotic arms. In each case, the visual feedback of an interactive experience is mechanically linked to a haptic device to provide an additional degree of realism and more accurately replicate the surgical experience simulated.

16.5 MECHANISMS OF TRANSLATIONAL NEUROSURGERY

Throughout this book, a number of new concepts and approaches to clinical neurosurgery have been described, many based on laboratory concepts that are in the process of translation to initial clinical experimentation. Many of these concepts and approaches will become clinical therapeutics at some level and many will eventually be rejected after they are tested. Great laboratory ideas often flounder in the setting of clinical applicability when unanticipated consequences arise. The formats of clinical trials most likely to be implemented with the advent of new therapeutics were outlined in Chapter 15.

Most of the different clinical trial formats require team approaches. One team member should be knowledgeable about the disease state to be treated and whether sufficient clinical interests or controversy exists to make a trial worthwhile. A team should also have a statistician or epidemiologist familiar with trial design who can help set up a suitable trial intended to answer the questions posed by the clinician. Such a trial may often involve multiple cooperating sites that are willing to rigidly follow a specific protocol. Various additional personnel are also needed to acquire and maintain data independently. A neurosurgeon should remain at the heart of any team, both to provide the clinical rationale and experience in clinical testing schemes and identify questions most suitable for study.

For devices there also needs to be a sponsor, such as an interested “enthusiastic” investigator, or more commonly, a corporate entity with commercial interests at heart. The sponsor is the liaison to the FDA for eventual approval and market release of the device (see Chapter 1). This group forms the minimum team needed to begin a clinical trial solution to a new product or device. However, one of the key components of such a team is the interested clinician, who can pose the critical problem,
which the clinical study or device will resolve, and who is sufficiently enthusiastic to maintain the trial format through the large number of regulatory and funding hurdles. The clinician needs to convince the community of other clinicians that resolution of the problem requires a formal clinical trial, establishing equipoise and uncertainty about the relative worth of differing treatment options.

Who will be these clinicians? As in Chapter 1, there is a large question as to whether or not this breed of clinician-investigators may be waning, particularly in surgical specialties such as neurosurgery. Unless there is a short payoff time from new device products to clinical applicability, neurosurgeons tend to lose interest in the problem, so maintaining a focus in spite of a more distant time to application is critical. The critical question at this time focuses on whether we are training such a blend of clinician investigators who will be sufficiently innovative and enthusiastic to skeptically approach current and future therapeutics, yet possess the critical training in both the basic science questions and clinical trials, to be able to address directly these critical concerns. The answer is not clear, nor the path to achieve this goal.

Clearly, one of the goals of neurosurgery training is to improve the specialty in the future by seeing that trainees are more involved with new approaches instead of the history of neurosurgery and be prepared to address future treatments and directions more appropriately and scientifically.

16.6 CONCLUSIONS

Neurosurgical training is very traditional, and not necessarily aimed at developing clinician investigators, particularly those who have bents toward translational neurosurgery or clinical investigation. Neurosurgery traditionally is a technical- and procedure-based specialty instead of having a research base. Critical and skeptical approaches to investigation are not necessarily highly valued within the specialty, particularly when the outcomes of investigations may result in limitation of practice or curtailing of procedures if results are negative.

Interest within neurosurgery is generally much greater in the history and development of neurosurgery than the development of translational approaches, particularly if the translational timeline to clinical application is greater than 2 or 3 years. Neurosurgery as a specialty could respond to such issues by altering the traditional approach to training, encouraging skeptical and investigational approaches to both judgment and technical aspects of neurosurgery, and aiding innovation even if it means curtailing procedures that have shown limited efficacy. A large number of innovational approaches to training now allow practitioners to hone their judgment and expand their knowledge of neurosurgical applications. Advances in simulation techniques and other technical advances will result in improvements in operative procedures. Whether these new approaches will be embraced and integrated into our training programs will be a critical question for the future.
REFERENCES