7 Training and Standards

Ephraim W. Church and Kevin M. Cockroft

Introduction

Between the 1960s and 2000s, neuroendovascular surgery has extensively and dramatically evolved [1, 2]. Initial efforts were aimed at high-risk "inoperable" vascular malformations. The 1970s saw microspheres and detachable coils introduced. Microcatheters, microwires, and liquid adhesives appeared in the 1980s. As recently as 1990, Guglielmi pioneered the electrolytically detachable coil. This remarkable story continues to unfold as technology and techniques continue to advance, most recently in the area of ischemic stroke.

Training programs appeared rapidly as neuroendovascular surgery progressed. Occasionally these programs were formed and fellows graduated with limited oversight [3]. Additionally, there has been considerable discussion regarding the steep learning curve of many neuroendovascular operations [4]. For example, Singh et al. reported a steep learning curve in their elective aneurysm embolization practice over a 7-year period. The complication rate dropped from 53 to 10% [5].

Both neuroendovascular and open cerebrovascular surgery may carry high morbidity. The risk of stroke from diagnostic cerebral angiography is 0.3–5.7%, and risk is increased in patients with cerebrovascular disease [6]. Surgeon competence increases in a linear fashion up to 100 cases, and up to 200 cases may be necessary for the trainee [7]. Neurological complication rates for coiling of cerebral aneurysms range from 5 to 14%. Morbidity may be as high as 11% for clipping of unruptured aneurysms [8]. Like neuroendovascular surgery, there is clearly a learning curve for open cerebrovascular surgery. It is evident that guidelines and oversight for training and granting of hospital privilege are essential for the continued success of vascular neurosurgery.

E.W. Church, M.D. • K.M. Cockroft, MD, MSc, FAANS, FACS, FAHA (✉)
Department of Neurosurgery, Penn State Milton S. Hershey Medical Center and Penn State University College of Medicine, Hershey, PA 17033, USA
e-mail: kcockroft@psu.edu

C.D. Gandhi, C.J. Prestigiacomo (eds.), *Cerebrovascular and Endovascular Neurosurgery*, https://doi.org/10.1007/978-3-319-65206-1_7

Neuroendovascular Training

Early Training Guideline Efforts

Although angiography was developed by neurologists and neurosurgeons, to a large extent, neurosurgeons left the field to develop open cerebrovascular surgery skills, harnessing the power of the operating microscope and microsurgical techniques. Meanwhile, radiologists developed new technologies and techniques in cerebral angiography. As neuroendovascular therapies become a reality, it was recognized that this new field would flourish only with close collaboration between neurosurgery and neuroradiology. Both fields bring essential knowledge and skill, and the greatest advances occurred at centers where teams of neuroradiologists and neurosurgeons worked together [9].

In 1994 there were more than 15 training programs in neuroendovascular surgery, but there was no formal process to ensure that both clinical skill and technique of trainees were thoroughly developed [9]. Initially, there was little opportunity for neuroendovascular training during residency. Significant modification of training programs would be necessary to incorporate new knowledge and skill. Early visionaries rejected the option of developing neuroendovascular and open cerebrovascular approaches in separate specialties because it is too easy to develop and propagate biased views about patient management. A hybrid form of training was needed.

The American Society of Neuroradiology (ASNR), the American Society of Interventional and Therapeutic Neuroradiology (ASITN), the American Association of Neurological Surgeons (AANS), and the Congress of Neurological Surgeons (CNS) developed informal recommendations for training guidelines as early as the 1990s [9]. This statement described paths for a physician with a radiology background and for a physician with a neurosurgical background. Both completed their respective residencies followed by 1–2 years of neuroendovascular surgery training (80–120 cases). For the radiologist, “a significant amount of time should be devoted to clinical neurosurgery with direct experience in neurointensive care management.” Similarly the neurosurgeon “must receive formal instruction in radiation physics and radiation protection.” Laboratory training should be incorporated into both pathways [9]. This early recommendation was followed by publication of a training program syllabus listing anatomic and physiologic knowledge, procedural aspects, pharmacology, and knowledge of cerebrovascular disease [9].

Joint Society Guidelines and Accreditation Council for Graduate Medical Education Program Requirements

The ASNR, ASITN, and the AANS/CNS Cerebrovascular Section developed and formally endorsed guidelines for training physicians in neuroendovascular surgery in 2000 [1, 10]. This document was remarkable in that it was 14 years in preparation and required considerable negotiations between governing bodies during a time when the field was still very young. Key features included training in the management of cerebrovascular disease, understanding of treatment options, performance of neuroendovascular surgery, and perioperative management. Other specified features were as follows:

1. Duration of training was 1 year.
2. The program director was certified by a governing body and had expertise in neuroendovascular surgery, concentrating at least 50% of his/her practice in this area.
3. There was at least one full-time faculty member per two residents.
4. There were at least 12 months of preparatory trainings, including theoretical and clinical training as well as at least 100 catheter-based diagnostic angiographic procedures. Following this, there were 12 continuous months of clinical training. Specific areas of training were delineated. There were daily ward rounds and regular conferences including morbidity and mortality. Residents were encouraged to attend at least one national conference or course.
5. The program performed at least 100 therapeutic neuroendovascular cases per year, which were of sufficient variety. The trainee maintained a case log.
6. Appropriate equipment and facilities were available.
7. There was an environment of inquiry and scholarship, and residents engaged in scholarly activities including research.
8. Residents were encouraged to interact with related specialties through conferences/teaching.
9. There were reasonable duty hours and work accommodations.
10. There was semiannual evaluation.

This document was well received by the specialties, although some commented that the training period should be lengthened. Although the guidelines represented a standard, there was no enforcing body. Individual programs were responsible for the quality of training.

Based on the joint society guidelines, the Accreditation Council for Graduate Medical Education (ACGME) published program requirements for graduate medical education in "endovascular surgical neuroradiology" in 2007 (revised as recently as 2016) [11, 12]. ACGME guidelines indicate that a fellowship in interventional neuroradiology, endovascular neurosurgery, or endovascular surgical neuroradiology should be jointly administered by ACGME-accredited programs in neurological surgery and neuroradiology at the same institution. The length of training should be 1 year. There is a prerequisite of exposure to catheter techniques (100 angiograms) along with exposure to neurointensive care and neurosurgical techniques. Training should include exposure to the full spectrum of cerebrovascular disease (specific areas are listed). Up-to-date equipment and space must be available. The program should foster an environment of knowledge development, and there should be a program director who regularly evaluates trainees.

Similar neurosurgery/neuroradiology collaborative efforts also occurred in Europe in the early 2000s. The Union of European Medical Specialists Section of Neurosurgery and the European Board of Neuroradiology proposed training standards and prescribed a training period of 2–3 years [13]. Prior to this, training standards in Europe often required prerequisite fellowship exams in radiology, making it difficult for neurosurgeons to enter the field [14]. There were similar efforts in Korea [15].

Current Training Guideline and Accreditation Efforts

Up to this point, training guidelines prescribed a hybrid of neurosurgical and radiological training. As the field matured, some argued successfully that this was no longer practical [16, 17]. While acknowledging the unique contributions of both neurosurgery and neuroradiology, many called for incorporation of neuroendovascular training into standard neurosurgery residency training. Neuroendovascular training was to be integrated into the neurosurgery residency, and residents with a particular interest would be free to pursue full training and certification during residency. Harbaugh argued that every ACGME requirement for training programs was currently fulfilled in neurosurgery residency, with the exception of performance of endovascular procedures and training in radiation physics, radiation biology, and radiation safety. These items could be added to the residency syllabus. In order for neurosurgeons to maintain a leadership role in the treatment of cerebrovascular disease, it was argued that neuroendovascular techniques must become part of the neurosurgery core curriculum. As an added benefit, mastery of angiogram interpretation would make neurosurgeons better at open cerebrovascular approaches. Moreover, patients will probably prefer surgeons who can perform all approaches and recommend whichever is best in their individual case.

An AANS Endovascular Task Force was asked to determine what might be done to ensure neuroendovascular surgery became the mainstream within neurosurgery. They offered several recommendations: first, an accelerated training pathway allowing neurosurgeons to perform a limited number of endovascular operations might be considered; second, neurosurgery programs should be required to introduce residents to endovascular techniques; and, third, they advocated continued close collaboration with interventional neuroradiology [16]. This effort led to incorporation of neuroendovascular knowledge and techniques in the ACGME/American Board of Neurological Surgery Milestone Project. A clear path for neuroendovascular training and certification of neurosurgical residents (and others) was delineated by the Committee on Advanced Subspecialty Training (CAST).

CAST is the most recent and most rigorous outline for training and certification in neuroendovascular surgery in the United States. This comprehensive program was agreed to by all the major societies involved in neuroendovascular work, including the Cerebrovascular Section of the AANS/CNS, the Society of Neurointerventional Surgery (SNIS), and the Society of Vascular Interventional Neurology (SVIN). CAST reports to the Council of the Society of Neurological Surgeons and is responsible for subspecialty training fellowships and certification in neurosurgical subspecialties. Recently published program requirements for neuroendovascular surgery include stipulations regarding setting, program director, faculty, and facilities/resources.

The fellowship training structure is outlined for neurosurgeons, neurologists, and radiologists. For the neurosurgeon, this includes completion of a 7-year ACGME residency. As a prerequisite, the candidate must perform at least 200 catheter-based diagnostic and/or interventional cerebral angiographic procedures. This is followed by 12 contiguous months of fellowship experience performed no sooner than PGY6. There must be a minimum of 250 interventional procedures, and minimum numbers of procedure types are specified. There are guidelines regarding documentation of clinical experience, conferences, and scholarly activity. Finally there are guidelines for supervision, duty hours, and evaluation [18, 19].

Individual Certification

In addition to program accreditation, in September of 2015, CAST began accepting applications for individual certification. All certificates are time-limited and will expire on December 31, 10 years after the date of issuance and/or concurrently with the timing of maintenance of certification renewal of the primary board certification (whichever comes first). General requirements for certification include completion of a neuroendovascular fellowship accredited by CAST and/or a fellowship with a similar structure as those accredited by CAST, board certification by the American Board of Neurological Surgery (ABNS) or the American Board of Medical Specialties (ABMS) of Radiology or Neurology, and a current, active, and unrestricted license to practice medicine in the United States. Of note, a “grandfather” system is currently in place until 2020. This “Practice Track” as it is known allows physicians who have already completed their primary board certification in neurosurgery, neurology, and/or radiology and have had additional training and/or experience in NES prior to the availability of CAST-accredited training programs to be eligible for CAST certification. To be considered for this program, applicants must have completed an ACGME-accredited residency training program in neurosurgery, neurology, or radiology with ABMS board certification. Applicants must also have completed a neuroendovascular fellowship or other equivalent trainings with a similar structure as those accredited by CAST and submit documentation of extensive neuroendovascular clinical practice experience. The entire application process can be completed online.

Other Training Initiatives

Spiotta et al. described a sequence of neuroendovascular milestones within neurosurgery residency training: core diagnostic angiography, advanced diagnostic angiography, guide catheter delivery, simple aneurysm embolization, and advanced aneurysm treatment [3]. They also made the case for simulation in neuroendovascular training. In one study, a group of residents performing angiography on a computer simulator were able to approximate fellows’ performance over the course of the trial [20]. The authors also argued for inclusion of neuroendovascular simulator training in neurosurgical residency.

Others have advocated neuroendovascular simulation training, particularly at the resident level [21, 22]. Fargen et al. piloted a simulator-based curriculum aimed at neurosurgical residents [23]. After a 2-day simulator course, seven neurosurgery residents showed significantly higher written test scores, technical skills ratings, improved surgery times, and reduced fluoroscopic time. This group went on to confirm these findings in a larger cohort [24]. Rabbit, pig, and synthetic models have also been developed for training purposes [25–30]. One group discussed the possibility of virtual reality training in neuroendovascular surgery, drawing on concepts from aviation training [31].

Standards in Neuroendovascular Surgery

Guidelines for Specific Operations

Standards for some operations have been published. Neurosurgery and neuroradiology societies collaborated to produce guidelines for carotid artery stenting (CAS) [6, 32]. These guidelines specify operator prerequisites and number of CAS to be performed under supervision (4) and independently. More recently, guidelines for thrombectomy for acute stroke have been published. A collaboration between multiple societies including neurosurgeons, neuroradiologists, and neurologists (the NeuroVascular Coalition) first defined adequate training for neuroendovascular procedures for ischemic stroke in 2009 [33]. Recommendations included completion of an ACGME-approved residency training program in neurosurgery, neuroradiology, or neurology and 1 year of neuroendovascular training. They recommended prior experience including at least 100 cerebral angiograms, documented training in microcatheter techniques, and at least ten cases as primary operator. Further, it was felt that physicians should have outcomes that meet national standards. Physicians should have ongoing stroke-specific continuing medical education (CME), procedures should be performed at comprehensive stroke centers, and there should be around-the-clock access to neurologists and neurosurgeons in order to manage complications of treatment.

These guidelines were recently updated by an impressive worldwide collaboration of numerous societies [34]. Baseline training qualifications include residency training in radiology, neurology, or neurosurgery and dedicated training in neuroendovascular surgery. It is vital that physicians engage in ongoing stroke-specific CME. Physicians should also participate in a quality assurance program and demonstrate successful recanalization (TICI 2b or 3) in at least 60%, embolization to new territory in less than 15%, and symptomatic intracranial hemorrhage in <10% of cases. The statement also describes hospital requirements, including availability of vascular neurosurgery expertise.

Hospital Privileges

Although guidelines for hospital privileges in neuroendovascular surgery have yet to be published formally, we expect this type of effort to be forthcoming. CAST certification, involvement in the maintenance of certification (MOC) process, and participation in a quality assurance program, such as a national registry, may well become required. Other related fields have published hospital privilege guidelines. For example, the Society for Vascular Surgery published guidelines for hospital privileges in vascular and endovascular surgery [35]. They suggest surgeons should have completed an ACGME-accredited vascular surgery residency. They provide guidelines for specific procedures. Lastly, they endorse both the Residency Review Committee for Surgery recommendations regarding open and endovascular case numbers in training and recommendations for credentialing in noninvasive vascular interpretation. Interventional radiology has likewise published statements regarding maintenance of privilege [36].

Maintenance of Certification

Hirsch et al. described the history and features of the MOC program in a publication for Society of NeuroInterventional Surgery (SNIS) members [37, 38]. Member boards of the American Board of Medical Specialties, including the American Board of Neurological Surgery (ABNS), received approval of MOC plans in 2006. MOC is based on six core competencies developed by the ACGME: professionalism, patient care and procedural skills, medical knowledge, practice-based learning and improvement, interpersonal and communication skills, and system-based practice. The four components of MOC are professional standing, lifelong learning, cognitive examination (every 7–10 years), and practice quality improvement. While the ABNS once granted lifetime certificates, time-limited certificates were granted starting in 1999. The MOC cycle consists of 3-year mini cycles. One must earn 150 h CME (at least 60 Category I in neurosurgery) and participate in the self-assessment in neurological surgery (SANS) examination each mini cycle. Practice quality improvement is assessed by submission of key cases and a tool for assessment, providing feedback about outcomes. Neuroendovascular is represented in this process with one of the recognized key cases being endovascular embolization of an anterior circulation aneurysm. The Quality Outcomes Database for Neurovascular (QOD-Neurovascular) a product of the NeuroPoint Alliance (NPA) an affiliate of the AANS is now operational and may aid in the practice quality improvement component of MOC. A similar quality database, the NeuroVascular Quality Initiative (NVQI) developed by the SNIS, is also available.

MOC efforts are occurring worldwide. The World Federation of Interventional and Therapeutic Neuroradiology published goals for maintenance of competence [39]. These include working in a comprehensive neuroscience center, completing at least 100 neuroendovascular cases in a 3-year period, maintenance of professional standing, satisfactory results of auditing, recertification every 5–10 years, and practice of continuous professional development (CPD). They define CPD “as the educative means of updating, developing and enhancing how doctors apply the knowledge, skills and attitudes required in their working lives.” Practitioners should also show a commitment to personal quality improvement.

Open Cerebrovascular Neurosurgery Training and Standards

A Changed Landscape: Fewer and More Complex Cases

While there are definite advantages to aneurysm clipping such as reliable occlusion, high rate of complete obliteration, and minimal chance of recurrence/hemorrhage, increasing numbers of aneurysms are being treated with neuroendovascular surgery [40]. The ISAT trial, published in 2002, probably did much to shift management toward endovascular treatment, but there were multiple contributing factors. Advantages of neuroendovascular surgery include shorter recovery and in many cases shorter operative time with lower short-term morbidity. Nevertheless, for the foreseeable future, there will remain many aneurysms for which clipping is the arguably most appropriate treatment modality. The presence of factors such as young patient age, hematoma, small size, and unfavorable branch relationships may continue to favor open surgical intervention. However, these can be difficult operations, requiring a degree of surgeon competence and resilience that can only be obtained with experience. Fewer training opportunities and more complex operations together form a significant challenge for the future of open cerebrovascular neurosurgery.

The reality of fewer open cerebrovascular training opportunities is well described. For example, Lai and Morgan reported a 53% reduction in microsurgical treatments of aneurysms in Australia between 2000 and 2008 [41], a time period spanning the publication of ISAT. The neurosurgical unit in Middlesborough, UK, reviewed all ruptured aneurysms treated in the pre-ISAT era from 1996 to 1999 [42]. They graded aneurysms for “ease of clipping” and “ease of coiling.” If all aneurysms considered endovascularly easy or moderate were coiled, only 17 of 172 or 4 per year would have been available for clipping. These authors note such a problem is not unique to neurosurgery. A similar dilemma was seen in urology with the development of percutaneous lithotripsy. Vascular and cardiothoracic surgeries have faced similar training challenges. Strategies to overcome the loss of training opportunities include sub-specialization and fellowship training. The authors also warn that long-term follow-up of endovascular treatments may reveal problems and we may see an increase in open cerebrovascular volume in the future. To a certain extent, this warning continues to apply today, 13 years later.

Other authors have investigated the importance of experience in open cerebrovascular neurosurgery. Le Reste et al. performed a retrospective review of poor-grade subarachnoid hemorrhage patients treated with clipping by five surgeons with different levels of experience. Not surprisingly, they discovered an association between less experience and intraoperative rupture [43]. Also documented is the likelihood that clipped aneurysms are, on the whole, more complex than previously. Sanai et al. reviewed a series of 218 posterior communicating artery aneurysms treated over an 11-year period and found complex aneurysms (large/giant size, fetal posterior communicating artery, previous coiling, anterior clinoidectomy, adherence of the anterior choroidal artery, intraoperative rupture, complex clipping, and atherosclerotic calcification) were less likely to have favorable outcomes. They argue that, because the simple aneurysms are now treated with endovascular embolization, neurosurgeons should change their expectations and learn techniques for clipping complex aneurysms [44].

In 2002, Roberto Heros published an essay titled “Training the cerebrovascular surgeon for the 21st century,” in which he traces the history of cerebrovascular neurosurgery and its present challenges [45]. He describes a golden era of cerebrovascular neurosurgery beginning in the 1970s with the operating microscope and the development of the EC-IC bypass. Many factors brought its decline including radiosurgery, less funding for research, and rapid progress in neuroendovascular surgery. He nevertheless argues that open cerebrovascular surgery is alive and well and should remain part of general neurosurgery training. Residents should be trained in a fully integrated open cerebrovascular/neuroendovascular service where they participate in the decision-making process regarding treatment methodology and care for both microsurgical and endovascular patients preoperatively and postoperatively. Heros points out that decision-making in vascular neurosurgery, best taught by example, is perhaps harder to master than the technical aspects, which are also complex. Fellowship training may help overcome loss of cases to neuroendovascular approaches, but exposure to a wide variety of cases will remain vital.

Others have advocated various different solutions for training in the setting of fewer but more complex cases. These include cadaveric and book study along with 3D preoperative planning [40] and surgical simulation [43, 46, 47]. Most agree that neurosurgery should maintain its leadership role in the treatment of cerebrovascular disease by training young neurosurgeons in both neuroendovascular and open cerebrovascular techniques. Neurosurgery residents seem to agree. Alshafai et al. sent a questionnaire regarding perceived competencies to residents from 45 countries who had completed their neurosurgical training recently. The vast majority thought that neuroendovascular and open management of aneurysms should be part of residency training (70.4% and 88.7%, respectively) [48].

Simulator Training and Fellowship Training

Much innovative work is being done in simulation training in open cerebrovascular neurosurgery [49]. Chugh et al. investigated the effect of a surgical rehearsal platform (SuRgical Planner) on aneurysm treatment with clip ligation. Their rehearsal platform offers the ability to practice a procedure prior to the operating room. In their study, time and number of clip attempts were improved following rehearsal [50]. Alaraj et al. created a real-time sensory haptic feedback virtual reality aneurysm clipping simulator (ImmersiveTouch). They tested the model on a group of residents who found it helpful overall [51]. Wong et al. devised a patient-specific virtual reality system for aneurysm clipping, as well as AVM resection (Dextroscope) [52, 53]. Future simulators will need to include representations of the brain surface and model brain and aneurysm deformation with retraction [49].

Aboud et al. created a model to simulate intraoperative aneurysm rupture, noting that rupture occurs in 9% of aneurysm surgeries [54]. Their “live” cadaver model includes artificial (sewn) and real (incidental) aneurysms, as well as artificial blood, which is irrigated through the cadaver head. Another group was able to 3D print patient-specific aneurysm models and implant them in human cadavers [55].

Surgery was then rehearsed. Others have described methods for the creation of hollow 3D aneurysm models [56, 57]. Even a human placenta model for microsurgical aneurysm clipping has been described [58].

Another potential solution for training of open cerebrovascular neurosurgery is support of fellowship training at high-volume cerebrovascular centers. The AANS/CNS Cerebrovascular Section maintains a database of both open cerebrovascular and neuroendovascular fellowships on their website. There are currently 11 open and 10 combined fellowships listed.

Guidelines for Competence

Neurosurgery residents graduating from an ACGME-accredited training program are considered competent in open cerebrovascular neurosurgery. Given the changing treatment patterns described above, this situation may change. Guidelines for competence may be needed in the near future if not already [41]. Here the CAST program may again play a role. Requirements for fellowship in cerebrovascular neurosurgery have been published [18, 19]. Prior to beginning the fellowship, the resident should have completed or be at a senior level in an ACGME-accredited neurosurgery training program. The standard length is 12 months. The experience should include participation in operative management of a wide range of cerebrovascular conditions, as well as study and research. At least 6 months must be spent in clinical activities. Expected characteristics, qualifications, or responsibilities of the sponsoring program, fellowship director, and faculty are outlined, but a volume of cases is not specified.

Recommendations

For Training Programs and Hospitals

- Take steps to further integrate neuroendovascular training into neurosurgery residency.
- Develop innovative strategies (potentially including virtual reality and simulation) for training future open cerebrovascular neurosurgeons in an era of fewer but more complex cases.
- Where appropriate, obtain CAST accreditation for training programs in neuroendovascular and open cerebrovascular surgery.
- Hire practitioners with CAST certification in neuroendovascular surgery.
- Acquire knowledge of credentialing guidelines for specific operations in order to ensure that physicians meet standards, recognizing that many operations have steep learning curves.
- Develop consensus standards for hospital privileges in neuroendovascular and open cerebrovascular surgery.

For Physicians

- Obtain CAST certification either through completion of a CAST-accredited fellowship or through the Practice Track pathway.

- Participate in MOC as outlined by the ABNS including CME, SANS, and practice quality improvement.
- Participate in a national registry (e.g., QOD-Neurovascular or NVQI) to advance knowledge and ensure outcomes meet national standards.

Conclusion

Dramatic changes in neuroendovascular and open cerebrovascular neurosurgery offer substantial challenges for neuroendovascular and open cerebrovascular neurosurgery. Significant progress has been made in training and certification in neuroendovascular surgery through the CAST program. Guidelines for hospital privileges and MOC remain important areas of effort in maintaining standards. There is a pressing need for innovation in training and maintenance of standards for open cerebrovascular techniques. We are confident that vascular neurosurgeons will rise to these challenges, ensuring the continued success of this exciting endeavor.

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