Society of Interventional Radiology

Training Guidelines for Intra-arterial Catheter Directed Treatment of Acute Ischemic Stroke

J.J. ("Buddy") Connors, III, MD, FSIR, David Sacks, MD, FSIR, Carl M. Black, MD, E. Bruce McIff, MD, FSIR, M. J. B. Stallmeyer, MD, PhD, John W. Cole, MD, MS, Howard A. Rowley, MD, Joan C. Wojak, MD, Robert A. Mericle, MD, Kieran J. Murphy, MD, FSIR and John F. Cardella, MD, FSIR

c/o Debbie Katsarelis
[1] CORRESPONDING ADDRESS:
3975 FAIR RIDGE DR, STE 400, NORTH
FAIRFAX, VA 22033
(703) 691-1805 OR (404) 616-6753
[FAX] (703) 691-1855

Introduction

In the United States, stroke is the leading cause of adult disability, the third leading cause of death, and a great personal fear of the general population. It ranks as the leading cause of expenditure of health care dollars and affects nearly 800,000 people per year. The fact that 10% of stroke victims die within 1 month and about one-third die after living 6 months with severe disability renders stroke of greater morbidity than cancer.(1-3) Data specifically concerning stroke related to angiographically proven occlusion of the main trunk of the middle cerebral artery (MCA) indicate that the early mortality rate may approach 25% to 30%.(4-6) Caplan et al. reported a 33% mortality rate in 3 months for main-trunk (M1) MCA occlusive stroke, decreasing to 14.3% if there were only a distal branch occlusion (M3).(7)

Intravenous (IV) tissue plasminogen activator (tPA) has proved clinically beneficial (modified Rankin Scale [mRS] 0-1 at 90 days) in only two trials (the National Institute of Neurologic Disorders and Stroke [NINDS] study: Part 2, and the European Cooperative Acute Stroke Study [ECASS] III).(8, 9) However, for the subset of patients with large vessel occlusion IV tPA has repeatedly been demonstrated to be of limited clinical benefit.(10-28) Large vessel occlusion can be documented by either the hyperdense MCA sign on non enhanced computed tomography (CT) or by intracerebral vascular imaging using CT angiography (CTA), magnetic resonance (MR) angiography (MRA), or catheter angiography. The hyperdense MCA sign has imperfect specificity (the occlusion might be larger than just the MCA), and limited sensitivity for large vessel occlusion (30-50%),(21, 29) but it is the only method available for analysis in the large randomized IV tPA trials.(30-32) At most, only 16% of patients with the hyperdense MCA sign in the ECASS(31) and NINDS(32) achieved good clinical outcomes (mRS 0-1) and IV tPA demonstrated no clinical benefit compared to placebo (17% good outcomes in NINDS),(32) not fully reported for ECASS.(31) Concerning risks, treatment of patients with hyperdense MCA with IV tPA resulted in 11% symptomatic intracranial hemorrhage (SICH) in NINDS compared to 2% for placebo.(32) The largest database in the world for acute stroke patients treated with IV tPA is the Safe Implementation of Thrombolysis in Stroke-MOnitoring Study (SITS-MOST)**.**(33, 34) In this database of 6483 patients, it was demonstrated that 1905 patients had the hyperdense MCA (29.3%), and of those, 16% had a favorable clinical outcome (mRS 0-1 at 90 days); in agreement with NINDS and ECASS. Large vessel occlusion confirmed by CTA, MRA, or catheter angiography typically causes severe stroke, independently predicts poor neurological outcome,(25, 30, 35) and is a stronger predictor of neurological deterioration than even early CT evidence of more than 50% MCA infarct.(35) Similar to patients with the hyperdense MCA sign, there are poor clinical outcomes after IV tPA treatment of image-confirmed large vessel occlusion. In a CTA study, patients without occlusions but treated with IV tPA had 0% bleeds vs. 23.3% (10% symptomatic) with large vessel occlusions (p=0.04).(20) In the Diffusion and perfusion imaging Evaluation For Understanding Stroke Evolution (DEFUSE) study large vessel occlusion with a favorable mismatch as demonstrated by MRI/MRA and treated by IV tPA achieved 33% mRS 0-2 at 30 days on average, with 44% mRS 0-2 when recanalized but 24% when not.(36) MRS 0-1 was not reported in DEFUSE. However, for those patients in DEFUSE that did achieve recanalization, 25% suffered symptomatic ICH versus 6% for those who did not.(36) Patients with no MRA occlusion had 0% symptomatic ICH,(36) the same as demonstrated with no CTA occlusion (20) and consistent with NINDS.(32) Thus, therapy with IV tPA of patients with large vessel occlusion is of limited clinical benefit.(1-34, 36-39)

While direct comparison with randomized IV tPA trials is not possible, intra-arterial (IA) treatment of MCA occlusion has demonstrated successful recanalization,(40-45) and also statistically significant clinical benefit (mRS 0-2 at 90 days). IA lysis of MCA occlusion has been studied in PROACT I (Prolyse in Acute Cerebral Thromboembolism),(40) PROACT II, (41) and MELT (middle cerebral artery embolism local fibrinolytic intervention trial (MELT) Japan).(42) In the double-blind randomized placebo-controlled trial PROACT II, 40% of treated patients achieved mRS 0-2 at 90 days as compared to 25% in the control group. MELT affirmed the positive clinical benefit of IA lysis for MCA occlusion, demonstrating statistically significant improvement in excellent clinical outcome (mRS 0 -1 at 90 days) in the IA urokinase group compared to the control group (42.1% vs. 22.8%, P=0.045, OR: 2.46, 95% CI: 1.09 to 5.54).(42) 35% of IA lysis patients in MELT had nearly complete neurological recovery (NIHSS 0-1 at 90 days) as compared to 14% in the control group (P=0.017).(42) MELT was prematurely halted due to approval of IV tPA in Japan for acute stroke, even though IV tPA has never been proved clinically beneficial in the specific group being tested in MELT (i.e. MCA occlusions), and thus MELT did not accrue enough patients to achieve statistical power for its primary endpoint (mRS 0-2 at 90 days). A direct comparison study of IA urokinase versus IV tPA for treatment of hyperdense MCA(37) demonstrated significantly better clinical outcomes (mRS 0-2 at 90 days) with IA urokinase (53% favorable outcome vs. 23%; p=0.001) These positive clinical results are supported by multiple case series.(10, 27, 37, 46) The American Stroke Association,(47) the American Heart Association,(48) and American College of Chest Physician(49) guidelines now recommend intra-arterial revascularization for selected patients. Estimates of potential candidates for intra-arterial revascularization range from 10,000-40,000 per year.(50, 51) These numbers are comparable to, or greater than, the number of acute stroke patients currently being treated with IV tPA and will require more physicians that are trained to provide intra-arterial stroke revascularization.(51)

The purpose of this document is to define the knowledge, training and experience necessary to competently provide quality patient care for emergency endovascular treatment of ischemic stroke. Formal neuroscience training is the base upon which to build acceptable clinical outcomes. Necessary components include clinical expertise in neurological examination and patient management, extensive microcatheter technical skill, and expertise in the interpretation of neuroimaging studies (neuroangiography, CT, MRI, cerebral perfusion, etc.) in order to guide case analysis, treatment planning, intraprocedural decisions and catheter management, and post-procedural care. Specific training guidelines are necessary due to the wide variety of interested clinical specialties (many of whom are already treating strokes without such guidelines), the wide range of clinical and angiographic presentations of ischemic stroke, and the complexity of the therapies. The physician treating acute stroke must have sufficient knowledge and training to master the complex endovascular techniques and cerebrovascular assessments necessary to make continuous critical decisions during the procedure itself. Without such expertise, the risks of neurological deterioration and death related to the endovascular procedure itself are unacceptably high and can outweigh the potential benefits of cerebral revascularization. In order to achieve acceptable outcomes, there is a need for strict oversight of performance of these personnel and procedures. These principles are consistent with the training requirements of the Accreditation

Council for Graduate Medical Education (ACGME)(52) and with previously published official statements from numerous medical societies.(53-55)

These guidelines have been developed by a consensus of experts to outline requirements for training in endovascular ischemic stroke interventions. These guidelines apply to physicians formally trained in these procedures and to those physicians whose primary specialty training did not include this care but did include adequate pre-requisites to support the training outlined herein. This document is intended for hospital credentialing, which is a mechanism by which competence is ensured and the quality of care is upheld for the patient, the hospital, and the community.

Risks of Cervicocerebral Endovascular Procedures

Risks of Diagnostic Cervicocerebral Angiography

Endovascular stroke interventions require expert skills not only in complex cerebral interventions, but also in diagnostic cervicocerebral angiography. Despite recent advances in noninvasive diagnostic neuroimaging, diagnostic cervicocerebral angiography remains the cornerstone and "gold standard" for the evaluation and treatment of patients with cerebrovascular disease,(56) and in particular, endovascular treatment of stroke. In addition to a high level of technical expertise required for safety, the performance and interpretation of diagnostic cervicocerebral angiography require in-depth cognitive knowledge of neurovascular anatomy and related neurological pathophysiology, including the neurodiagnostic and pathological possibilities encountered in acute ischemic stroke. Evaluating real-time procedural images when the vasculature is not completely visualized due to occlusion is necessary during the performance of the procedure and requires a high level of expertise.

The risk of permanent neurological deficit as a result of diagnostic cerebral angiography ranges from 0.2-5.7%.(57-76) The risk of procedure-induced stroke has been a reason for some physicians to not recommend cerebral angiography, and contributes to the reluctance of some patients to undergo the procedure.(57, 71-73) However, with modern equipment and well trained practitioners, complication rates should be lower than 1%.(66, 70) The largest series of cases to date reported a permanent neurological deficit or death of less than 0.2%.(74-76) Patients with symptomatic atherosclerotic cerebrovascular disease (ipsilateral transient ischemic attack [TIA] or stroke) have a 2-3 fold higher risk of stroke from diagnostic cerebral angiography (0.5-5.7% risk of permanent deficit) as compared to asymptomatic patients (0.1-1.2% risk).(57-61, 66-70, 73) Operator experience, as measured by decreased complications and decreased fluoroscopy time necessary for the performance of a cervicocerebral angiogram, improves in a linear fashion up to 100 cases.(61)

In addition to the technical risks of cerebrovascular procedures, there is also the risk of misdiagnosis if angiographic images are not interpreted correctly. For example, studies of coronary angiography performed by fellowship trained interventional cardiologists demonstrate errors between observers' assessments of only one variable, coronary stenosis, ranging from 15% to 45%.(77) The risks of inter-observer variation are likely far higher when considering the more complex cerebrovascular anatomy. This is particularly true in situations where major vascular landmarks are missing due to vascular occlusions. Erroneous interpretation and lack of appreciation of key findings may result in unnecessary interventional procedures, denial of essential treatment, or incorrect treatment during a procedure. The risk to the patient of variability in interpretation will be significantly increased if the physician performing and interpreting cervicocerebral angiography and emergency stroke therapy lacks appropriate formal training.

The Risks of Emergency Endovascular Stroke Therapy

Endovascular interventions are higher-risk procedures than diagnostic angiography. Endovascular interventions for acute ischemic stroke are associated with symptomatic intracranial hemorrhage in approximately 10% of treated patients, of which more than 50% will be fatal.(78) Treatment of acute ischemic stroke requires superselectively accessing intracranial arteries that are occluded by clot (and thus frequently angiographically invisible), therefore creating the potential for inadvertent microvascular perforation with potentially fatal results. These selective microcatheterization tasks are particularly risky since the occluded vessels float in cerebrospinal fluid, have extremely acute angulations, and do not have the robust wall support that is present in other vascular territories. Further, lysis of clot can result in reperfusion of brain that might be nonviable and result in brain swelling, hemorrhage, and/or death.

Risks of emergency endovascular stroke therapy are mainly of two types: 1) those that are the result of the primary insult that may not be fully understood, appreciated, or predictable, and 2) those caused by operator technical errors or misjudgements. Some complications can be identified as being technical in nature, such as a large subarachnoid hemorrhage (SAH) caused by a vascular perforation, or a visible air embolus (usually seen on follow-up CT). While there were no reported incidents of SAH in the PROACT trials, subarachnoid bleeds were reported in the Mechanical Embolus Removal in Cerebral Ischemia (MERCI) and Penumbra trials that utilized mechanical devices.(43, 44, 79)

The first trials to study emergency endovascular stroke therapy were PROACT and PROACT II.(80, 81) Both the phase II PROACT I and the randomized, placebo-controlled phase III PROACT II trials demonstrated statistically positive clinical benefit for treating M-1/M-2 segment MCA occlusions. In order to maintain low operator complication rates, both trials mandated specific procedural detail that included not traversing the occlusion into unseen vascular territory. Symptomatic intracerebral hemorrhage (ICH) occurred in 12 of the 110 patients (10.9%) treated with recombinant prourokinase (r-proUK) and in two of the 64 (3.1%) who received IV heparin alone. Of the 12 patients treated with IA lytic that developed ICH, 10 died, resulting in a mortality rate of 83%. All of these hemorrhages occurred in the area of the acute infarct and had the first onset of ICH related symptoms at a mean of 10.2 +/- 7.4 hours after the outset of treatment. The MELT trial (42) demonstrated a similar rate of unspecified intracranial bleeding of 9% in the urokinase treated patients but with only one death at 90 days from hemorrhage. However, there was one guidewire perforation and one case of air embolism.

The risk of symptomatic intracranial hemorrhage after thrombolysis for acute ischemic stroke is substantial, regardless of whether the agent is infused by the IV or IA route. The rate of symptomatic ICH in IV tPA treated patients was 6.4% in the NINDS study,(8) 8.8% in ECASS II(82) and 7.2% in the Alteplase Thrombolysis for Acute Noninterventional Therapy in Ischemic Stroke (ATLANTIS) study.(83) In the presence of confirmed MCA occlusion (Hyperdense MCA in NINDS), the symptomatic ICH rate was 11% in NINDS using IV tPA,(32) 10% in PROACT II using IA urokinase,(41) and 9% (combined symptomatic and asymptomatic ICH in MELT) using IA urokinase.(42)

The depth and duration of ischemia varies in all patients suffering a large vessel stroke and thus the risk of hemorrhagic transformation will never be completely eliminated. This situation is clearly different from that of ICH that occurs in the setting of IV tPA use in patients with acute myocardial infarction in whom the ICH occurs randomly in the brain parenchyma in the absence of acute abnormalities in the cerebral circulation. In addition to hemorrhage into the cerebral infarct, IV or IA tPA use for emergency stroke treatment can also produce systemic bleeding (e.g., gingival and intestinal).(20, 84, 85) In peripheral arterial occlusions systemic bleeding seems to be more common with intra-arterial use of tPA as compared to intra-arterial use of urokinase.(86) The above factors may be related to severity of tissue damage or choice of lytic agent, but not necessarily technical factors.

Use or non-use of a lytic agent does not necessarily solely determine the rate of hemorrhage, morbidity or mortality. In the Interventional Management of Stroke studies (IMS) I and II, clot was displaced into a previously uninvolved anterior cerebral artery in 1.7% of M1/M2 therapeutic procedures, and in 3/20 ICA-T occlusions.(87) Use of mechanical clot retrievers carries increased and unique risks such as vascular perforation (with high risk of mortality). Utilizing thrombectomy devices, displacement of thrombotic material to a previously uninvolved territory (such as the anterior cerebral artery) can occur while withdrawing the embolic clot from the original site of occlusion.(87-89) In the original MERCI trial,(44) procedural complications occurred in 13% of cases and 7.1 % (10/141) were clinically significant. Vascular dissection is more common with this mechanical device (reported in 4 cases), and frank subarachnoid hemorrhage was observed in at least 5 cases and was likely caused by vascular perforation.(44) Symptomatic intracranial hemorrhage occurred in 11/141 patients (7.8%) and 5/11 bleeds were subarachnoid hemorrhage, indicative of the stress placed on these fragile intracranial vessels by the mechanical devices.(44) Symptomatic intracranial hemorrhage occurred at the same frequency in patients who had adjunctive lytic therapy as compared to those with mechanical intervention alone. However, in patients whose occlusion was located in the MCA, the hemorrhage rate was only 6%, lower than in PROACT with similar occlusion sites.(44) Overall, however, there were far more operator caused procedural complications in mechanical clot retrieval cases than in IA lytic infusion cases. The vascular perforation rate in the MERCI trial was 4.3%,(44) which is similar to the 3.8% seen in the combined IV/IA lysis IMS study(90) and 2.9% using endovascular photoacoustic recanalization.(91) All of these trials were performed by experienced and trained neurointerventionists. The overall mortality rate in the MERCI trial was 44%. In the pooled analysis of the MERCI and Multi MERCI trials, it was found that hemorrhage rates were 6% for recanalized cases but 16.7% for the non-recanalized group.(92) Hemorrhage rates were not affected by prior intravenous use of lytic agents. Three perforations occurred, all of which were fatal. Unspecified procedural complications occurred in 12.8% of patients in the pivotal Penumbra Stroke Trial.(45)

Emergency endovascular stroke therapy is perhaps the most difficult and risky of the many cerebral, peripheral, and coronary endovascular procedures. Errors in diagnostic judgment and technical procedural errors are easily made without adequate specific training. Therefore, appropriate and adequate cognitive and technical training and proficiency as well as sufficient clinical experience are absolutely essential for the safe performance of these procedures.

Training

Introduction

Official standards of training for all medical specialties have existed for over a quarter century, are the hallmark of medical licensure, board examinations, residency programs, individual physician privileges and hospital credentialing. Official standards of training are recognized as mandatory by the Accreditation Council for Graduate Medical Education, the Federation of State Medical Boards of the United States, Inc., the American Board of Medical Specialties (ABMS), and the National Board of Medical Examiners®.(53-55) Practicing within the appropriate scope of training is a fundamental rule of medical care. Furthermore, continuing assessment of competence is mandated by the Centers for Medicaid and Medicare Services as well as state medical licensing boards in the form of Continuing Medical Education (CME) credits.(93-95) The Joint Commission (JC) is working with two other accrediting organizations, the National Committee for Quality Assurance and URAC (formerly known as the Utilization Review Accreditation Commission), on coordinating and aligning patient safety standards.(96-98) The Joint Commission, in association with the American Stroke Association, has established guidelines for primary stroke centers based upon recommendations from the Brain Attack Coalition that include quality of service standards for diagnostic cervicocerebral angiography.(99) The Brain Attack Coalition has also established guidelines for Comprehensive Stroke Centers that mandate cognitive and technical neurovascular training and expertise in order to perform endovascular stroke therapy.(100)

Training guidelines and required training experience for diagnostic arteriography and endovascular intervention for multiple vascular territories have been published and endorsed by numerous medical societies including the American Heart Association (AHA), the American College of Cardiology (ACC), the Society of Vascular Surgery (SVS), the Society of Interventional Radiology (SIR), the American Society of Neuroradiology (ASNR), and the Society of NeuroInterventional Surgery (SNIS, formerly the American Society of Interventional and Therapeutic Neuroradiology - ASITN).(101-122) Guidelines from the AHA, ACC, SVS, SIR, ASNR, and SNIS mandate the performance of at least 100 diagnostic angiograms regardless of the vascular bed as one basic requirement for the performance of endovascular interventions.

The need for extensive training in organ specific vascular interventions is emphasized in the training required to perform coronary interventions. The ACC recognizes that endovascular coronary interventions carry a higher risk than diagnostic coronary angiography and requires significant additional training.(123) Cognitive training concerning the pathophysiology of the heart in addition to credentialing in performance of diagnostic coronary angiography is a prerequisite for training in coronary intervention.(105, 109-112) In addition to the core 24 month training period and 300 diagnostic coronary angiograms required for a diagnostic cardiologist, the ACC recommends a full 20 months of supervised cardiac catheterization lab training with at least 250 supervised coronary stent procedures as the minimum acceptable requirements before a practitioner is judged competent to perform coronary interventions, including treatment of acute myocardial infarction.(113-117) The ABMS has not only affirmed that high degrees of training are necessary for appropriate and safe cardiac patient care but acknowledged this high level of achievement in the form of a Certificate of Added Qualification (CAQ) for Interventional Cardiology.(124) The result of these requirements is that fully trained diagnostic cardiologists are not permitted or credentialed to treat an acute myocardial infarction with endovascular techniques, even though they have performed over 300 coronary angiograms at an ACGME approved training site. The principles of competency, cognitive knowledge, and adequate specialty training are necessarily as crucial for the performance of emergency endovascular treatment of cerebral infarction as they are for emergency endovascular treatment of myocardial infarction.

Continuous clinical, procedural, and cerebrovascular angiographic assessment, and crucial moment-to-moment decision-making are fundamental parts of any surgical/endovascular interventional procedure. Thus all necessary knowledge must reside in the individual actually performing the procedure. We recognize the necessity of at least three components of adequate training for competency to perform endovascular interventional procedures for acute ischemic stroke.

1) Formal training that imparts an adequate depth of cognitive knowledge of the brain and its associated pathophysiological vascular processes, clinical syndromes and the full array of ischemic stroke presentations,

2) Procedural skill, including management of complications secondary to these endovascular/surgical procedures, that is achieved by repetitive supervised training in an approved clinical setting by a qualified instructor, and

3) Diagnostic and therapeutic acumen, including the ability to recognize procedural/angiographic complications. This is achieved by studying, performing and correctly assessing a large number of diagnostic and interventional/endovascular procedures with proper tutelage.

This training document differs from prior training requirements developed to promote physician competency. Traditionally, training requirements have not been based on definitive evidence but rather have been set by consensus based on a belief that meeting such requirements will lead to satisfactory patient outcomes. In addition, training requirements have typically been based on time spent training rather than competency as defined by quantifiable measures. We recognize that training is meant to provide a physician with the tools necessary to produce satisfactory outcomes for patient care. Rather than focus only on time spent training, in this document we focus on knowledge that must be acquired and subsequent mastery demonstrated by examination. We do include a requirement for time and case experience, including proctoring by an experienced mentor, but we believe that successful proctoring can rely on electronic means of communication such as telephones and teleradiology.

While dedicated training in vascular interventions must be the basis for endovascular stroke rescue, focused education and experience in the clinical care of a stroke patient and in specific procedural methods for stroke rescue should supplement that training and lead to good practice. A dedicated neurointerventional fellowship (Endovascular Surgical Neuroradiology – ESN) should provide such education and experience.(125) ACGME oversight of educational programs requires documentation of fulfillment of these educational objectives.(52) Excellent clinical outcomes for intra-arterial stroke therapy have been demonstrated by physicians who have not completed an ACGME neurointerventional fellowship.(46) It is expected that a structured training program as outlined in this document will further enhance the ability of all interventionists to treat stroke. The effectiveness of these training guidelines will be assessed by mandatory measurement of clinical outcomes. These outcomes will be tracked for the purposes of documenting acceptable performance relative to previously published trials and ongoing contemporary results and compared nationally. These aggregated outcomes submitted to a national database will be reviewed by the Society of Interventional Radiology over the three years from publication of the standards. Should outcomes data related to stroke therapy from dedicated neurointerventional fellowships be available at that time, these data will also be compared.

We recognize that practitioners from a variety of backgrounds currently have developed endovascular skills outside the neuraxis. These skills alone are insufficient to perform emergency endovascular stroke therapy, just as the ability to evaluate and treat patients with laparoscopic hysterectomy does not confer the ability to evaluate and treat patients requiring laparoscopic colectomy. The consensus is that a defined amount of formal cognitive training specifically related to stroke and cerebrovascular disease is essential for any physician to perform diagnostic cervicocerebral angiography, interventional intracerebral procedures, and in particular, endovascular therapy of acute stroke. Therefore, in addition to procedural and technical experience requirements, a minimum of 6 months of formal cognitive post graduate neuroscience training is necessary to become competent in the interventional care of patients with acute ischemic stroke. This training must, at a minimum, include neuroanatomy, cerebrovascular hemodynamics, stroke syndromes, stroke mimics, collateral cerebrovascular pathways, clinical neurological examination (including the NIH Stroke Scale), clinical neurological findings related to specific vascular ischemic insults, and neuroimaging of acute stroke by techniques such as such as CT, MRI, CTA, MRA, cerebral angiography, and CT/MR and nuclear cerebral perfusion studies. Fulfillment of the ACGME training requirements for radiology, neuroradiology, neurosurgery, neurology, vascular neurology, and fellowship training in neurointerventions provide this cognitive knowledge if adequately enhanced with stroke-specific training. This defined training applies to all practitioners who wish to be credentialed to perform intra-arterial acute ischemic stroke interventions. These cognitive assets and technical skills can be obtained during routine specialty training, or may be acquired later, but are essential in order to achieve competency and to assure proper patient outcomes.

Existing Standards

Cognitive Training In Cerebrovascular Disease

Specific cognitive training in cerebrovascular disease is included in the ACGME residency requirements for diagnostic radiology, neurology, and neurosurgery. The mandatory required knowledge base includes neurological and neurovascular anatomy, neuropathophysiology, neurologic imaging, and clinical neurological correlation.(126) The cognitive knowledge base required to pass board certification examinations in these residencies includes an understanding of stroke syndromes and etiologies, diagnostic studies including carotid ultrasound, brain CT and MRI, transcranial Doppler, cerebral angiography, CT angiography, MR angiography, CT and MR perfusion, Positive Emission Tomography (PET), Single Photon Emission Computed Tomography (SPECT), and the evaluation of a broad range of neurological conditions, including tumors, seizures, and other stroke mimics. These neurological conditions also include traumatic and/or atherosclerotic neurovascular lesions, evaluation of acute stroke in all its forms, recognition of cerebrovascular flow and perfusion abnormalities, and recognition of vascular inflammatory conditions of the central nervous system. Post residency training in neuroradiology, vascular neurology, and endovascular surgical neuroradiology is also available through ACGME approved subspecialty programs.(127-129)

Diagnostic Cervicocerebral Angiographic Training

Competence in cervicocerebral diagnostic angiography is mandatory for the performance of any neurointerventional endovascular procedure. The American Academy of Neurology (AAN) recommends 100 appropriately supervised cervicocerebral angiograms as a minimum for required training and credentialing for neurointervention in stroke.(120, 121) Training and quality improvement guidelines for adult diagnostic cervicocerebral angiography have been published by the American College of Radiology (ACR), SNIS, ASNR and the SIR.(101, 106) Recognizing that far larger numbers of cerebrovascular assessments are now routinely performed non-invasively using CT angiography or MR angiography, and that there is now extensive exposure to these noninvasive angiograms in some specialties, the current recommendation from the ACR for credentialing for diagnostic cervicocerebral catheter angiography is 50 cases, supplemented by other general angiographic and non-invasive neurovascular imaging experience. Radiology, neuroradiology, and ACGME-approved Endovascular Surgical Neuroradiology training programs (that only allow entry from neurosurgery, neurology, or neuroradiology) (129) are the only ACGME-approved medical specialties that require cervicocerebral catheter angiography training.(127, 130)

Interventional Cervicocerebral Training

The ACGME has acknowledged the need for advanced training for the full spectrum of endovascular interventions involving the cervicocerebral and intracranial vasculature by officially recognizing the discipline of Endovascular Surgical Neuroradiology.(129) This

ACGME-approved Endovascular Surgical Neuroradiology training program explicitly incorporates additional training in clinical neurocritical care, as well as thorough training in advanced endovascular neuroradiological procedural techniques.(129) The ACGME-defined program of Endovascular Surgical Neuroradiology specifically requires training in the indications, contraindications and technical aspects of endovascular treatment modalities of acute ischemic stroke.(129) The defined program also mandates 100 diagnostic cervicocerebral angiograms prior to training in this neurointerventional specialty.(122) This requirement is not altered by prior angiographic experience in any other vascular territories and is similar in concept to the requirements to perform peripheral arterial angioplasty.(102-105, 107)

For endovascular treatment of acute ischemic stroke SNIS, AAN, the Society of Vascular and Interventional Neurology (SVIN), and the American Association of Neurologic Surgeons/Congress of Neurological Surgeons (AANS/CNS) require the same training as that necessary to perform the full spectrum of endovascular neurointerventions: a year of Endovascular Surgical Neuroradiology fellowship.(125)

The authors of this document do not believe that an entire neurointerventional fellowship is required for appropriate and successful endovascular treatment of acute ischemic stroke. In contrast to the training requirements to perform the full spectrum of endovascular neurointerventions, allowance is made in this document for the performance of the specific procedure of endovascular treatment of acute ischemic stroke based on the technical skills and cognitive knowledge that can be acquired through alternate advanced training and surrogate experience. Such experience is the performance of large numbers of selective catheter arteriograms, microcatheter experience in other vascular beds, and cognitive expertise gained from supervised training and interpretation of large numbers of cerebral CT and MR angiograms in addition to cerebrovascular catheter arteriograms. Excellent stroke outcomes have been achieved by physicians with these skills and abilities.(46) In order to treat acute ischemic stroke with catheter-directed revascularization, the prerequisite physician training in cerebrovascular anatomy and hemodynamics should include at least 200 selective vascular catheterizations of which at least 50 should be cervicocerebral angiograms. Further, prerequisite knowledge includes interpretation of at least 200 cervicocerebral catheter angiograms, at least 50 CTA examinations, 50 MRA examinations, and 25 noninvasive cerebral perfusion studies (CT perfusion/MR perfusion/SPECT). This knowledge base can be acquired during routine ACGME training or in postgraduate dedicated stroke training.

Augmentation of Training

Simulator training has been shown to be of benefit in limited medical applications for acquiring additional technical skills.(131-138) However, appropriate formal training in the neurosciences and neuroimaging, combined with adequate experience in cervicocerebral angiography and intervention in an approved clinical training program has no adequate substitute in contemporary medical practice. Future trainees may benefit from added training on medical simulators for additional technical procedural skills, as well as added study of neurological processes and stroke. At the present time, simulator equipment is neither perfected nor validated for training purposes in the cervicocerebral and/or intracerebral vasculature. Consistent with

ACGME training standards and the ACC training standards (COCATS 2), we emphasize that in the absence of formal neuroscience training industry-sponsored seminars, continuing medical education (CME) coursework, and self-taught learning alone are insufficient for credentialing related to endovascular stroke therapy. Augmentation of knowledge and skills may be an arduous task, but is always possible and is the crux of continuing education. Significant stroke-specific neurointerventional training is available and can supplement a particular individual's technical and cognitive strengths.

Maintenance and Assurance of Continuing Quality of Care

Procedures that involve the intracranial vasculature are inherently risky and endovascular stroke therapy requires the highest level of competency. Proficiency is maintained by lifelong continuing medical education as well as continuing performance of cases with adequate success and outcomes with minimal complications. Quality Assurance and continuing improvement are necessary for high quality healthcare regardless of which discipline might be involved in treating patients. The quality improvement process is a patient oriented process, designed to ensure a minimum baseline level of quality and predictable outcomes, and represents in many ways a safety net for the credentialing process. A post-hoc quality assurance process does not substitute for adequate and appropriate physician training leading to acceptably skilled practitioners suitable for credentialing. A quality assurance process should confirm that procedures are performed for appropriate indications with rates of success and complications that meet acceptable standards. Such Quality Improvement standards have been published for diagnostic cerebral angiography as well as extracranial carotid stenting(101, 106, 120, 139) but are not yet available for endovascular treatment of acute ischemic stroke.

Due to the importance of continually assessing performance, an interventional stroke therapy outcomes registry, preferably multi-institutional or national in scope, is necessary to monitor ongoing processes as well as procedural results and clinical outcomes. Outcomes should be tracked and recorded. Submission of outcomes to a registry with national participation (such as the ***IN***terventional ***S***troke ***T***herapy ***O***utcomes ***R***egistry [***INSTOR***]) (140) is required. This is useful for ongoing quality assurance/improvement as well as comparison to outcomes from comparable facilities. Appropriate outcomes should be achieved both during the training period and following granting of privileges in order to ensure maintenance of competence. At this time there is insufficient information to know if maintenance of competence requires annual performance of a specific numbers of cases, but data from other vascular interventional procedures such as coronary stenting, coronary artery bypass grafting, carotid stenting, and carotid endarterectomy indicate that, in general, greater experience confers better outcomes.(141-143)

Specific Recommendations Regarding Physician Qualifications to Perform Intra-arterial Catheter Directed Treatment of Acute Ischemic Stroke

Continuous clinical and procedural assessment, careful judgment and crucial on-going decision-making are fundamental parts of any surgical/endovascular interventional procedure, and thus all of the listed qualifications are considered basic qualifications and must be met by the individual performing the procedure. More advanced ancillary expertise may be provided by other members of a stroke team. Sufficient training to meet the basic qualifications should be provided in a Neurointerventional Fellowship and should include documented experience treating acute ischemic strokes as primary operator,(125) either within an accredited Endovascular Surgical Neuroradiology program or an equivalent non-accredited program. Such training should include attestation by the fellowship director that the fellow has achieved adequate experience(124) and is competent to independently treat strokes.

For those lacking formal neurointerventional fellowship training, specific training is necessary to perform catheter-directed stroke therapy. Technical ability is demonstrated with superselective microcatheter experience in other vascular beds and with training in neuro specific technical skills as described below. Cognitive requirements should also be part of an intensive continuing or graduate medical education (CME or GME) course or training curriculum dedicated to catheter-directed stroke therapy, as described below and summarized in the Table A. Adequate training is documented by 1) passing a written examination to assess cognitive knowledge (see Appendix), 2) direct observation of technical skills as listed in the appendix and assessment of the ability to integrate cognitive and technical skills, 3) being proctored for initial procedures with acceptable outcomes, and 4) demonstrating satisfactory outcomes by submitting all cases to a national registry such as the ***IN***terventional ***S***troke ***T***herapy ***O***utcomes ***R***egistry [***INSTOR***] (140) to be compared to benchmarks.

Physician and Facility Requirements for Intra-arterial Catheter Directed Treatment of Acute Ischemic Stroke

A. Cognitive qualifications in neuroanatomy, pathophysiology, hemodynamics, and clinical correlations for ischemic and hemorrhagic stroke:

1. Certification to perform the NIH stroke scale.
2. A minimum of 6 months of formal neuroscience training is required that includes the study of stroke and its causes, clinical neurological examination including the NIH stroke scale, neuroanatomy, neuropathology, cerebrovascular anatomy and hemodynamics, and comprehensive neuroimaging (e.g. CT, CTA, CT perfusion, multimodal MRI, carotid and transcranial Doppler, nuclear SPECT, cerebral angiography, and PET, etc.).
3. A dedicated CME stroke-specific educational course (mentioned above) or GME curriculum is required and should also contain certain mandatory cognitive elements described below. The training in imaging interpretation (brain CT, MRI, CTA, MRA, CT/MR perfusion, and cervicocerebral angiography) can be part of a supervised residency/fellowship program incorporating this field of study or can be part of an approved training program using a teaching file with the program directed by a physician with ACGME approved training and board certification in the interpretation of those studies. This program, in whole or in part, could be available either as a separate training course or as part of a dedicated

endovascular stroke-therapy training course or as part of an ACGME graduate training program. These elements are:

a. Knowledge of clinical presentation of ischemic and hemorrhagic stroke. This should include understanding of the clinical presentations of ischemic insults in specific vascular territories, anterior versus posterior circulation strokes, cortical versus lacunar strokes, and clinical presentation of stroke mimics. The ability to perform and/or confirm the findings of a clinical examination for these presentations is a necessary skill for the primary operator performing acute catheter-directed stroke therapy.
b. Ability to recognize the clinical and imaging patterns of early and late infarction, hemorrhage, other masses and non-space occupying lesions (which could clinically mimic stroke) on a CT scan of the brain. Minimal training must include interpretation, reporting, and/or supervised review of 200 brain CT studies, including at least 50 with early signs of acute stroke, including examples of all pathologies and/or complications potentially encountered in this therapy.
c. Ability to diagnose hyperacute/acute hemorrhage, early and late infarction, other masses and non-space occupying lesions (which could clinically mimic stroke) on MRI, including conventional and diffusion weighted sequences. Interpretation, reporting, and/or supervised review of 200 brain MRI studies, including at least 50 cases with early signs of acute ischemic stroke with diffusion weighted MRI sequences.
d. Ability to recognize stenotic, embolic, and thrombo-occlusive cerebrovascular lesions on catheter angiography, MRA and CTA. Minimal training must include interpretation, reporting, and/or supervised review of 50 cerebral MRA and 50 CTA studies.
e. Familiarity with and ability to recognize acute and chronic ischemia on cerebral perfusion imaging techniques such as perfusion CT or perfusion MR. Minimal training must include interpretation, reporting, or supervised review of 25 cerebral CT and/or MR perfusion studies.
f. Knowledge of cervico-cerebrovascular anatomy and pathophysiology including collateral flow patterns, stenoses of varied etiologies, occlusion recognition, anatomic variants, mass effect, extravasation, hyper and hypoperfusion, abnormal arteriovenous transit time, and other neurovascular conditions demonstrated on cerebral angiograms. Minimal training must include interpretation, reporting, and/or supervised review of the cerebral arteriographic procedures performed under requirement number B-1, plus interpretation of additional cerebral arteriographic procedures for a total of at least 200 procedures. A procedure is defined as a bilateral carotid and at least a unilateral vertebral arteriogram with intracranial imaging.
g. Knowledge of techniques, indications, and contraindications for intra-arterial catheter based treatment of acute ischemic stroke, including clinical indications and relative and absolute contraindications. Such instruction shall be included in the training program and/or a dedicated stroke therapy training course or as part of an ACGME-approved graduate training

program.

h. Knowledge of clinical pharmacology and proper use and dosing of commonly used thrombolytic agents, vasodilators (used either by intra-arterial or intravenous means), and antiplatelet agents. Further, the ability to treat hypertension and other procedural or clinical complications potentially encountered in the acute setting is necessary. This information must be incorporated into training and included in any dedicated stroke therapy training course or as part of an ACGME-approved graduate training program.

i. The knowledge acquired (a – h) shall be verified by a test. The test content is listed in the appendix.

B. Technical qualifications for catheter-directed pharmacologic stroke therapy

For those lacking fellowship training in an Endovascular Surgical Neuroradiology fellowship program that includes sufficient documented treatment of acute ischemic strokes as primary operator, training is required for hands-on review of techniques in the use of Y-connectors, tubing, catheter flushing techniques, air embolus prevention, guide catheters, microcatheters, and all equipment necessary for performing intracranial stroke thrombolysis. The instructor for this must have met the training requirements of this document. The instructor must certify that the trainee has mastered these technical skills.

AND

1. Documentation of prior experience performing cerebral angiography and/or selective arterial catheterization as described below:

   a. Performance on at least 100 patients of selective carotid and/or vertebral arteriograms with outcomes that must meet or exceed the benchmarks set by the American College of Radiology (ACR) guideline for cervicocerebral angiography for success and complications.

   OR

   b. Performance on at least 200 patients of percutaneous selective vascular catheterization procedures in any vascular bed including at least 50 patients with selective carotid and/or vertebral catheterizations. For the cerebral studies, outcomes must meet or exceed the benchmarks set by the ACR guideline for success and complications.

AND

2. Prior experience using microcatheter/microguidewire (3 French or less) systems including performance of at least 30 interventional arterial cases using the selective placement of microcatheters and microwires into 3rd order or higher branches including at least 5 cases of selective internal (ICA) or external carotid artery (ECA) branch catheterization.

   AND

   a. At least 5 catheter-directed intracranial stroke lysis cases with all cases as primary operator under the direct supervision of a proctoring physician who has privileges to perform this procedure and has personally performed at least 10 catheter-directed intracranial stroke lysis cases with acceptable outcomes.

   OR

b. Additional training at a site that performs neurointerventional stroke procedures under the supervision of a proctoring physician who has privileges to perform these procedures and has personally performed at least 10 catheter-directed intracranial stroke lysis cases with acceptable outcomes. For the physician to be considered qualified, at the end of this training, the proctor must certify that the physician has adequate technical and cognitive skills.

After this training period, the first 5 live cases of acute stroke therapy shall have additional proctoring during the case with a suitably qualified stroke expert whose job is to be available during the case for telephone and/or teleradiology advice.

C. Technical qualifications for use of intracranial mechanical devices for stroke therapy

Mechanical revascularization (thrombectomy/embolectomy) devices have not yet been confirmed to improve patient outcomes. In addition, it is not possible to define general training requirements when there has been no demonstrated clinically significant benefit for any mechanical revascularization clot retrieval devices. There is consensus that the skills needed and risks associated with use of these devices are much greater than the skills needed and risks associated with use of catheter-based pharmacologic lysis, and therefore it is not possible to make specific training recommendations at this time. However, at a minimum, the physician must meet the training criteria described herein for pharmacologic lysis for emergency stroke therapy and have successfully completed a training course for use of any specific device.

D. Pre-existing credentials

All physicians already credentialed to perform intra-arterial catheter-directed stroke procedures prior to the publication of these standards should have outcomes that are acceptable by institutional or national standards. If the practitioner has limited experience, the above training requirements, while not mandatory, are recommended. All cases should be entered into a national database/registry for purposes of quality assurance.

E. Maintenance of qualifications

1. The physician should have ongoing stroke specific CME of at least 15 hours/2 years.
2. The physician should have procedure outcomes that are acceptable by institutional or national standards as indicated by participation in a national registry.
3. Outcomes performance
   a. While the definition of adequate training is extensive in this document, it is mandatory that the facility and physician verify the satisfactory performance of these procedures and confirm good outcomes and maintain qualifications to perform these procedures. Therefore it is mandated that all patients being treated for ischemic stroke with endovascular therapies be entered into a national registry and that all 90-day outcomes be recorded and submitted to such registry to document adequate quality and satisfactory performance.

Facility Qualifications and Requirements

1. The facility at which these procedures are performed must have stroke treatment processes of care and quality assessment programs that optimize stroke outcomes. Certification by the Joint Commission as a primary stroke center is the ideal method of assuring the presence of these processes. The facility should have physicians capable of managing pre- and post procedure neurocritical care of endovascularly treated stroke patients. There must be 24/7 availability of neurosurgical care in order to treat possible complications of stroke therapy.
2. There must be an active quality assurance program for stroke therapy to monitor outcomes both in the periprocedural period and at 90 days. All emergency interventional stroke therapy patients must be routinely reviewed by the quality assurance program. Outcomes must be tracked and recorded. Submission of outcomes to a registry with national participation is required.(140)

Conclusions

High standards are required for adequate quality and safe performance of neurointerventional therapies for patients with acute stroke. These procedures can result in a significant clinical benefit for stroke patients but can also confer significant risks. Credentials committees at each institution are charged with enforcing adequate standards of training and experience for initial accreditation in all procedures, surgeries and treatments. In particular, to maximize patient safety and assure physician competency, credentialing criteria for endovascular treatment of acute ischemic stroke must be rigorous and uniform across all specialties. Furthermore, credentialing committees should certify and require prospective training criteria as well as quality improvement programs that are consistent with mandated and accepted standards as defined by the ACGME, individual medical specialties, the ABMS, and all individual state medical licensing boards. Due to the potential for grave consequences to the patient secondary to inadequate or deficient training, formal neuroscience training as specified herein is required. These guidelines are supported by peer-reviewed published standards and should be mandated for emergency endovascular stroke therapy, analogous to vascular interventions for acute myocardial infarction or other highly morbid conditions.(108-121)

Table A: Summary of Training Requirements

Cognitive

1. Understanding of and certification in assessing the NIHSS
2. 6 months ACGME formal neuroscience training including neuroanatomy, neuropathology, neurovascular imaging, and cerebrovascular hemodynamics
3. Stroke specific training in clinical presentation of stroke and associated vascular territories
4. Training in stroke specific exams for stroke mimics and conversion reactions
5. Ability to evaluate neuroimaging for determination of appropriate patients for acute stroke treatment
6. Ability to differentiate acute ischemic lesions as compared to chronic lesions and/or tumors, etc.
7. Ability to differentiate TIA from acute infarct
8. Ability to recognize etiology of TIA and acute stroke, including stenosis and embolus
9. Knowledge of cerebrovascular hemodynamics as it relates to perfusion imaging, and clinical presentation
10. Knowledge of pharmacological agents used for acute stroke therapy
11. Understanding peri-procedural and post-procedural hemodynamics and implications for appropriate patient care

Brain Imaging

12. Interpretation of 200 CT and 50 CTA
13. Interpretation of 200 MRI and 50 MRA
14. Interpretation of 25 CT/MR perfusion
15. Interpretation of 200 cerebral arteriogram interpretations

Technical

16. Hands on equipment experience
17. Arteriography performance
    a. 100 cerebral (bilateral carotid and at least single-vessel vertebrobasilar injections)
       or
       50 cerebral and 150 non cerebral
    b. 30 selective microcatheter procedures including 5 ICA/ECA

Stroke

18. 5 proctored in person
    or
    Visiting training and 5 proctored electronically/telephonically

Facility Requirements

19. Primary stroke center or equivalent

20. Quality assurance program specifically assessing stroke patients, acute stroke treatments, and clinical outcomes
21. Facility support for submission of all cases to a national stroke registry for interventional stroke therapy

APPENDIX – TEST CONTENT

1. PATIENT SELECTION AND EVALUATION

A. <u>Imaging Competencies</u>

1. Essential neuroanatomy
2. Brain CT and MR scan interpretation
    a. CT appearance of stroke and stroke mimics (parenchymal hemorrhage, subdural or subarachnoid hemorrhage, mass lesions, etc.)
    b. MR appearance of stroke and stroke mimics (white matter diseases, posterior reversible encephalopathy syndrome, venous thrombosis, inflammatory/infections processes, etc)
3. Cervicocerebral CT angiogram interpretation
4. Cervicocerebral MR angiogram interpretation
5. Ability to identify penumbra from completed infarction with functional imaging
    a. Brain CT perfusion scan interpretation
    b. Brain MR perfusion and diffusion scan interpretation
6. Interpretation of transcranial Doppler scans
7. Angiographic imaging
    1. Knowledge of cerebrovascular anatomy
    2. Normal anatomic variants (trigeminal artery, etc.)
    3. Circle of Willis variations)
    4. Identification of superficial and deep watershed areas on cerebral angiography
    5. Ability to distinguish lesions likely to produce hypoperfusion and watershed vs. embolic infarcts
    6. Expected values of flow rate of various vessels (i.e. CCA, ICA, ECA, MCA, vertebral, basilar)
    7. Functional neuroangiography:
        a. Variations in cervical and cerebral arterial trunk and branch development
        b. Common pathways of collateral flow
        c. “Dangerous” collateral vascular supply to intracranial vessels
        d. Assessment of pathways and adequacy of collateral flow beyond vascular occlusions
    8. Relationship of angiographic abnormalities to clinical abnormalities
    9. Assessment of treatment strategies for angiographically demonstrated lesions related to potential for improving clinical outcome of stroke

10. Ability to recognize complications of intracranial thrombolysis by changes in angiographic appearance (vessel perforation, vessel displacement, embolization, dissection, intracranial flow rate, etc.)

B. Clinical Competencies

1. Knowledge of functional cerebral/cerebellar anatomy (recognition of functional Brodmann's areas and key white matter pathways on routine and functional neuroimaging examinations, and the relationship of the functional regions to vascular territories)
2. Knowledge of stroke syndromes associated with various vascular occlusions, including ability to distinguish cortical from lacunar from posterior fossa infarcts, pure motor syndromes, and posterior fossa syndromes such as Wallenberg
3. NIHSS
    a. Competence to perform the NIHSS (completion of NIHSS course and test)
    b. Sample videos of assessment of various parts of the NIHSS and scoring for that portion of the exam, including:
        i. How to score visual impairment
        ii. How to score walking, etc
        iii. Ability to distinguish dysarthria from aphasia
    c. Implications of various NIHSS scores
        i. Estimation of occlusion location
        ii. Likelihood of large vs. small vessel occlusion
4. Rankin Score – competence to perform a Modified Rankin Score with completion of course and test
5. Clinical presentation of stroke mimics
6. Assessment of a conversion reaction
7. Natural history of stroke based on prior trials stratified for risk factors
8. Assessment of risk/benefit of stroke intervention based on age, NIHSS, blood glucose, size of lesion on CT or MR, duration of symptoms, clot location, collateral flow, and ischemic penumbra
9. Based on outcomes from IA and IV trials: ability to explain risks and benefits of various therapies
    1. IV
    2. IV as bridge to IA
    3. IA
    4. Mechanical thrombectomy

II. TECHNICAL ABILITY TO PERFORM INTRA-ARTERIAL THROMBOLYTIC THERAPY

1. Diagnostic cerebral angiographic technique
    a. Arch anatomy and catheter selection

   b. Complete vs. targeted angiography
   c. Superselective microcatheter angiography
   d. Injection rates
2. Intra-arterial revascularization technique
   a. Choice of proper sheath/guide catheter
   b. Ability to properly hook-up flush to sheath
   c. Use of diagnostic and guide catheters
   d. Proper use of guidewires with guide catheters
   e. Proper choice of placement of guidecatheter tip
   f. Safe catheter exchange
   g. Choice of appropriate exchange wire
   h. Preparation and use of flush systems to avoid air emboli and clots
   i. Proper set-up of Y-connectors
   j. Proper hookup of Y-connector to guide catheter with no bubbles and adequate flush
   k. Proper use of tubing and microbore tubing
   l. Use of air filters
   m. Choice of microcatheters and microwires
   n. Safe manipulation of microcatheters and microwires; proper curves
   o. Pitfalls of microcatheter use and dangerous maneuvers, rescue techniques from complications of microcatheterization
   p. Techniques of injecting flush/contrast in the cerebral vasculature and/or past an occlusion
   q. Infusion techniques
      i. Anticoagulants
      ii. Lytics
      iii. Infusion rates
   r. Management of reperfusion; strategies for when to pursue occlusions, how to assess for residual occlusions, catheter and wire choice for distal branch access
   s. When to stop a revascularization attempt
   t. Indications for leaving an arterial sheath after completion of procedure
3. Closure devices – indications and risks

III. CLINICAL MANAGEMENT

1. Management of blood pressure pre/during/post procedure
   a. Acceptable ranges of blood pressure
      i. Residual occlusion
      ii. No residual occlusion
   b. Hyperperfusion syndromes
2. Management of coagulopathy
3. Management of intracranial hemorrhage
4. Use of intracranial thrombolytics, antiplatelets, anticoagulants, and reversal agents
5. Proper technique for infusion of drugs
6. Proper technique for mixing drugs or agents to be infused
7. Proper rate of infusion of drugs or agent

8. Correct dosing of lytic agents or other drugs
9. Management of moderate sedation
10. Knowledge of pharmacological agents necessary during a case
    a. Pressors
    b. Antihypertensives
    c. Lytics
    d. Heparin
    e. Diuretics
    f. Direct thrombin inhibitors
    g. Antiplatelets
    h. Blood transfusions
    i. Platelet transfusion
    j. Sedatives
    k. Fluid management
    l. Narcotics
11. Implementation of written protocols and order sets
    a. Pre-procedure evaluation
    b. Post thrombolytic therapy management
    c. Management of hemorrhagic stroke
12. Risk factor management
    a. Timely work-up of TIA
    b. Primary differential considerations
    c. Indications for longer-term anticoagulation and antiplatelet therapy
13. Understanding the role and timing of physical therapy and rehabilitation

References:

1. Kappelle LJ, Adams HP, Jr., Heffner ML, Torner JC, Gomez F, Biller J. Prognosis of young adults with ischemic stroke. A long-term follow-up study assessing recurrent vascular events and functional outcome in the Iowa Registry of Stroke in Young Adults. Stroke. 1994;25:1360-1365.
2. Vogel J. [5 years follow-up study of stroke patients over 65 years of age]. Rehabilitation (Stuttg). 1994;33:155-157.
3. Zeumer H, Freitag HJ, Zanella F, Thie A, Arning C. Local intra-arterial fibrinolytic therapy in patients with stroke: urokinase versus recombinant tissue plasminogen activator (r-TPA). Neuroradiology. 1993;35:159-162.
4. Andreoli A, Limoni P, DeCarolis P, et al. Prognosis of middle cerebral artery occlusion. Copoerative study on 1978 cases. In: Spetzler R, Selman W, Carter LOP, Martin MA (eds.). Cerebral revascularization for stroke. New York: Theime/Grune and Stratton, 1985, pp. 53-56.
5. Moulin DE, Lo R, Chiang J, Barnett HJ. Prognosis in middle cerebral artery occlusion. Stroke. 1985;16:282-284.
6. Saito I, Segawa H, Shiokawa Y, Taniguchi M, Tsutsumi K. Middle cerebral artery occlusion: correlation of computed tomography and angiography with clinical outcome. Stroke. 1987;18:863-868.
7. Caplan LR, Hier DB, D'Cruz I. Cerebral embolism in the Michael Reese Stroke Registry. Stroke. 1983;14:530-536.
8. Tissue plasminogen activator for acute ischemic stroke. The National Institute of Neurological Disorders and Stroke rt-PA Stroke Study Group. N Engl J Med. 1995;333:1581-1587.
9. Hacke W, Kaste M, Bluhmki E, Brozman M, Davalos A, Guidetti D, et al. Thrombolysis with alteplase 3 to 4.5 hours after acute ischemic stroke. N Engl J Med. 2008;359:1317-1329.
10. Arnold M, Schroth G, Nedeltchev K, Loher T, Remonda L, Stepper F, et al. Intra-arterial thrombolysis in 100 patients with acute stroke due to middle cerebral artery occlusion. Stroke. 2002;33:1828-1833.
11. Lee KY, Kim DI, Kim SH, Lee SI, Chung HW, Shim YW, et al. Sequential combination of intravenous recombinant tissue plasminogen activator and intra-arterial urokinase in acute ischemic stroke. AJNR Am J Neuroradiol. 2004;25:1470-1475.
12. Pfefferkorn T, Mayer TE, Opherk C, Peters N, Straube A, Pfister HW, et al. Staged escalation therapy in acute basilar artery occlusion: intravenous thrombolysis and on-demand consecutive endovascular mechanical thrombectomy: preliminary experience in 16 patients. Stroke. 2008;3:1496-1500.
13. Saqqur M, Uchino K, Demchuk AM, Molina CA, Garami Z, Calleja S, et al. Site of arterial occlusion identified by transcranial Doppler predicts the response to intravenous thrombolysis for stroke. Stroke. 2007;38:948-954.
14. Zaidat OO, Suarez JI, Santillan C, Sunshine JL, Tarr RW, Paras VH, et al. Response to intra-arterial and combined intravenous and intra-arterial thrombolytic therapy in patients with distal internal carotid artery occlusion. Stroke. 2002;33:1821-1826.

15. Perren F, Loulidi J, Graves R, Yilmaz H, Rufenacht D, Landis T, et al. Combined IV-intra-arterial thrombolysis: a color-coded duplex pilot study. Neurology. 2006;67:324-326.
16. Sekoranja L, Loulidi J, Yilmaz H, Lovblad K, Temperli P, Comelli M, et al. Intravenous versus combined (intravenous and intra-arterial) thrombolysis in acute ischemic stroke: a transcranial color-coded duplex sonography--guided pilot study. Stroke. 2006;37:1805-1809.
17. Sugiura S, Iwaisako K, Toyota S, Takimoto H. Simultaneous treatment with intravenous recombinant tissue plasminogen activator and endovascular therapy for acute ischemic stroke within 3 hours of onset. AJNR Am J Neuroradiol. 2008;29:1061-1066.
18. Cross DT, 3rd, Derdeyn CP, Moran CJ. Bleeding complications after basilar artery fibrinolysis with tissue plasminogen activator. AJNR Am J Neuroradiol. 2001;22:521-525.
19. Zaidat OO, Suarez JI, Sunshine JL, Tarr RW, Alexander MJ, Smith TP, et al. Thrombolytic therapy of acute ischemic stroke: correlation of angiographic recanalization with clinical outcome. AJNR Am J Neuroradiol. 2005;26:880-884.
20. Sims JR, Rordorf G, Smith EE, Koroshetz WJ, Lev MH, Buonanno F, et al. Arterial occlusion revealed by CT angiography predicts NIH stroke score and acute outcomes after IV tPA treatment. AJNR Am J Neuroradiol. 2005;26:246-251.
21. Tomsick T, Brott T, Barsan W, Broderick J, Haley EC, Spilker J, et al. Prognostic value of the hyperdense middle cerebral artery sign and stroke scale score before ultraearly thrombolytic therapy. AJNR Am J Neuroradiol. 1996;17:79-85.
22. Cross DT, 3rd, Moran CJ, Akins PT, Angtuaco EE, Diringer MN. Relationship between clot location and outcome after basilar artery thrombolysis. AJNR Am J Neuroradiol. 1997;18:1221-1228.
23. Jansen O, von Kummer R, Forsting M, Hacke W, Sartor K. Thrombolytic therapy in acute occlusion of the intracranial internal carotid artery bifurcation. AJNR Am J Neuroradiol. 1995;16:1977-1986.
24. Shaltoni HM, Albright KC, Gonzales NR, Weir RU, Khaja AM, Sugg RM, et al. Is intra-arterial thrombolysis safe after full-dose intravenous recombinant tissue plasminogen activator for acute ischemic stroke? Stroke. 2007;38:80-84.
25. Smith WS, Tsao JW, Billings ME, Johnston SC, Hemphill JC, 3rd, Bonovich DC, et al. Prognostic significance of angiographically confirmed large vessel intracranial occlusion in patients presenting with acute brain ischemia. Neurocrit Care. 2006;4:14-17.
26. Sylaja PN, Dzialowski I, Krol A, Roy J, Federico P, Demchuk AM. Role of CT angiography in thrombolysis decision-making for patients with presumed seizure at stroke onset. Stroke. 2006;37:915-917.
27. Agarwal P, Kumar S, Hariharan S, Eshkar N, Verro P, Cohen B, et al. Hyperdense middle cerebral artery sign: can it be used to select intra-arterial versus intravenous thrombolysis in acute ischemic stroke? Cerebrovasc Dis. 2004;17:182-190.
28. Bendszus M, Urbach H, Ries F, Solymosi L. Outcome after local intra-arterial fibrinolysis compared with the natural course of patients with a dense middle cerebral artery on early CT. Neuroradiology. 1998;40:54-58.
29. Flacke S, Urbach H, Keller E, Traber F, Hartmann A, Textor J, et al. Middle cerebral artery (MCA) susceptibility sign at susceptibility-based perfusion MR imaging: clinical importance and comparison with hyperdense MCA sign at CT. Radiology. 2000;215:476-482.
30. Moulin T, Cattin F, Crepin-Leblond T, Tatu L, Chavot D, Piotin M, et al. Early CT signs in acute middle cerebral artery infarction: predictive value for subsequent infarct locations and outcome. Neurology. 1996;47:366-375.

31. Manelfe C, Larrue V, von Kummer R, Bozzao L, Ringleb P, Bastianello S, et al. Association of hyperdense middle cerebral artery sign with clinical outcome in patients treated with tissue plasminogen activator. Stroke. 1999;30:769-772.
32. Nichols C, Khoury J, Brott T, Broderick J. Intravenous recombinant tissue plasminogen activator improves arterial recanalization rates and reduces infarct volumes in patients with hyperdense artery sign on baseline computed tomography. J Stroke Cerebrovasc Dis. 2008;17:64-68.
33. Kharitonova T, Ahmed N, Thoren M, Wardlaw JM, von Kummer R, Glahn J, et al. Hyperdense middle cerebral artery sign on admission CT scan--prognostic significance for ischaemic stroke patients treated with intravenous thrombolysis in the safe implementation of thrombolysis in Stroke International Stroke Thrombolysis Register. Cerebrovasc Dis. 2009;27:51-59.
34. Kharitonova T, Thoren M, Ahmed N, Wardlaw JM, von Kummer R, Thomassen L, et al. Disappearing hyperdense middle cerebral artery sign in ischaemic stroke patients treated with intravenous thrombolysis: clinical course and prognostic significance. J Neurol Neurosurg Psychiatry. 2009;80:273-278.
35. Manno EM, Nichols DA, Fulgham JR, Wijdicks EF. Computed tomographic determinants of neurologic deterioration in patients with large middle cerebral artery infarctions. Mayo Clin Proc. 2003;78:156-160.
36. Albers GW, Thijs VN, Wechsler L, Kemp S, Schlaug G, Skalabrin E, et al. Magnetic resonance imaging profiles predict clinical response to early reperfusion: the diffusion and perfusion imaging evaluation for understanding stroke evolution (DEFUSE) study. Ann Neurol. 2006;60:508-517.
37. Mattle HP, Arnold M, Georgiadis D, Baumann C, Nedeltchev K, Benninger D, et al. Comparison of intraarterial and intravenous thrombolysis for ischemic stroke with hyperdense middle cerebral artery sign. Stroke. 2008;39:379-383.
38. Lin K, Rapalino O, Law M, Babb JS, Siller KA, Pramanik BK. Accuracy of the Alberta Stroke Program Early CT Score during the first 3 hours of middle cerebral artery stroke: comparison of noncontrast CT, CT angiography source images, and CT perfusion. AJNR Am J Neuroradiol. 2008;29:931-936.
39. Torres-Mozqueda F, He J, Yeh IB, Schwamm LH, Lev MH, Schaefer PW, et al. An acute ischemic stroke classification instrument that includes CT or MR angiography: the Boston Acute Stroke Imaging Scale. AJNR Am J Neuroradiol. 2008;29:1111-1117.
40. del Zoppo GJ, Higashida RT, Furlan AJ, Pessin MS, Rowley HA, Gent M. PROACT: a phase II randomized trial of recombinant pro-urokinase by direct arterial delivery in acute middle cerebral artery stroke. PROACT Investigators. Prolyse in Acute Cerebral Thromboembolism. Stroke. 1998;29:4-11.
41. Furlan A, Higashida R, Wechsler L, Gent M, Rowley H, Kase C, et al. Intra-arterial prourokinase for acute ischemic stroke. The PROACT II study: a randomized controlled trial. Prolyse in Acute Cerebral Thromboembolism. JAMA. 1999;282:2003-2011.
42. Ogawa A, Mori E, Minematsu K, Taki W, Takahashi A, Nemoto S, et al. Randomized trial of intraarterial infusion of urokinase within 6 hours of middle cerebral artery stroke: the middle cerebral artery embolism local fibrinolytic intervention trial (MELT) Japan. Stroke. 2007;38:2633-2639.

43. Smith WS. Safety of mechanical thrombectomy and intravenous tissue plasminogen activator in acute ischemic stroke. Results of the multi Mechanical Embolus Removal in Cerebral Ischemia (MERCI) trial, part I. AJNR Am J Neuroradiol. 2006;27:1177-1182.
44. Smith WS, Sung G, Starkman S, Saver JL, Kidwell CS, Gobin YP, et al. Safety and efficacy of mechanical embolectomy in acute ischemic stroke: results of the MERCI trial. Stroke. 2005;36:1432-1438.
45. The penumbra pivotal stroke trial: safety and effectiveness of a new generation of mechanical devices for clot removal in intracranial large vessel occlusive disease. Stroke. 2009;40:2761-2768.
46. Belisle JG, McCollom VE, Tytle TL, Banowetz JM, Handley RA, Andrezik JA, et al. Intraarterial therapy for acute ischemic strokes. J Vasc Interv Radiol. 2009;20:327-333.
47. Adams HP, Jr., del Zoppo G, Alberts MJ, Bhatt DL, Brass L, Furlan A, et al. Guidelines for the early management of adults with ischemic stroke: a guideline from the American Heart Association/American Stroke Association Stroke Council, Clinical Cardiology Council, Cardiovascular Radiology and Intervention Council, and the Atherosclerotic Peripheral Vascular Disease and Quality of Care Outcomes in Research Interdisciplinary Working Groups: the American Academy of Neurology affirms the value of this guideline as an educational tool for neurologists. Stroke. 2007;38:1655-1711.
48. 2005 American Heart Association Guidelines for Cardiopulmonary Resuscitation and Emergency Cardiovascular Care. Circulation. 2005;112:IV1-203.
49. Albers GW, Amarenco P, Easton JD, Sacco RL, Teal P. Antithrombotic and thrombolytic therapy for ischemic stroke: American College of Chest Physicians Evidence-Based Clinical Practice Guidelines (8th Edition). Chest. 2008;133:630S-669S.
50. Cloft HJ, Rabinstein A, Lanzino G, Kallmes DF. Intra-arterial stroke therapy: an assessment of demand and available work force. AJNR Am J Neuroradiol. 2009;30:453-458.
51. Hirsch, JA, Yoo AJ, Nogueira RG, et al. Case volumes of intra-arterial and intravenous treatment of ischemic stroke in the USA. J NeuroInterv Surg. 2009; 1:27-31.
52. ACGME. Outcome Project. Available at: http://www.acgme.org/Outcome/. Accessed October 12, 2009.
53. Armbruster JS. Accreditation of residency training in the US. Postgrad Med J. 1996;72:391-394.
54. Redman HC. The route to subspecialty accreditation. Radiology. 1989;172:893-894.
55. Langsley DG. What is the American Board of Medical Specialties? Pathologist. 1985;39:30-32.
56. Cerebral arteriography. A report for health professionals by the Executive Committee of the Stroke Council, American Heart Association. Circulation. 1989;79:474.
57. Heiserman JE, Dean BL, Hodak JA, Flom RA, Bird CR, Drayer BP, et al. Neurologic complications of cerebral angiography. AJNR Am J Neuroradiol. 1994;15:1401-1407.
58. Mani RL, Eisenberg RL. Complications of catheter cerebral arteriography: analysis of 5,000 procedures. II. Relation of complication rates to clinical and arteriographic diagnoses. AJR Am J Roentgenol. 1978;131:867-869.
59. McIvor J, Steiner TJ, Perkin GD, Greenhalgh RM, Rose FC. Neurological morbidity of arch and carotid arteriography in cerebrovascular disease. The influence of contrast medium and radiologist. Br J Radiol. 1987;60:117-122.

60. Earnest Ft, Forbes G, Sandok BA, Piepgras DG, Faust RJ, Ilstrup DM, et al. Complications of cerebral angiography: prospective assessment of risk. AJR Am J Roentgenol. 1984;142:247-253.
61. Dion JE, Gates PC, Fox AJ, Barnett HJ, Blom RJ. Clinical events following neuroangiography: a prospective study. Stroke. 1987;18:997-1004.
62. Moran CJ, Milburn JM, Cross DT, 3rd, Derdeyn CP, Dobbie TK, Littenberg B. Randomized controlled trial of sheaths in diagnostic neuroangiography. Radiology. 2001;218:183-187.
63. Grzyska U, Freitag J, Zeumer H. Selective cerebral intraarterial DSA. Complication rate and control of risk factors. Neuroradiology. 1990;32:296-299.
64. Horowitz M, Duton K, Purdy PD. Assessment of complication types and rates related to diagnostic angiography and interventional neuroradiologic procedures. Interventional Neuroradiology. 1998;4:27-37.
65. Dawkins AA, Evans AL, Wattam J, Romanowski CA, Connolly DJ, Hodgson TJ, et al. Complications of cerebral angiography: a prospective analysis of 2,924 consecutive procedures. Neuroradiology. 2007;49:753-759.
66. Willinsky R, Taylor SM, terBrugge K, et al. Neurologic complications of cerebral angiography: Prospective analysis of 2,899 procedures and review of the literature. Neuroradiology. 2003;227:522-528.
67. Kerber CW, Cromwell LD, Drayer BP, Bank WO. Cerebral ischemia. I. Current angiographic techniques, complications, and safety. AJR Am J Roentgenol. 1978;130:1097-1103.
68. Endarterectomy for asymptomatic carotid artery stenosis. Executive Committee for the Asymptomatic Carotid Atherosclerosis Study. JAMA. 1995;273:1421-1428.
69. Mani RL, Eisenberg RL, McDonald EJ, Jr., Pollock JA, Mani JR. Complications of catheter cerebral arteriography: analysis of 5,000 procedures. I. Criteria and incidence. AJR Am J Roentgenol. 1978;131:861-865.
70. Johnston DC, Chapman KM, Goldstein LB. Low rate of complications of cerebral angiography in routine clinical practice. Neurology. 2001;57:2012-2014.
71. Berteloot D, Leclerc X, Leys D, Krivosic R, Pruvo JP. [Cerebral angiography: a study of complications in 450 consecutive procedures]. J Radiol. 1999;80:843-848.
72. Hankey GJ, Warlow CP, Molyneux AJ. Complications of cerebral angiography for patients with mild carotid territory ischaemia being considered for carotid endarterectomy. J Neurol Neurosurg Psychiatry. 1990;53:542-548.
73. Davies KN, Humphrey PR. Complications of cerebral angiography in patients with symptomatic carotid territory ischaemia screened by carotid ultrasound. J Neurol Neurosurg Psychiatry. 1993;56:967-972.
74. Kaufmann TJ, Huston J, 3rd, Mandrekar JN, Schleck CD, Thielen KR, Kallmes DF. Complications of diagnostic cerebral angiography: evaluation of 19,826 consecutive patients. Radiology. 2007;243:812-819.
75. Fifi JT, Meyers PM, Lavine SD, Cox V, Silverberg L, Mangla S, et al. Complications of modern diagnostic cerebral angiography in an academic medical center. J Vasc Interv Radiol. 2009;20:442-447.
76. Trystram D, Dormont D, Gobin Metteil MP, Iancu Gontard D, Meder JF. [Imaging of cervical arterial dissections: multi-center study and review of the literature]. J Neuroradiol. 2002;29:257-263.

77. Leape LL, Park RE, Bashore TM, Harrison JK, Davidson CJ, Brook RH. Effect of variability in the interpretation of coronary angiograms on the appropriateness of use of coronary revascularization procedures. Am Heart J. 2000;139:106-113.
78. Kase CS, Furlan AJ, Wechsler LR, Higashida RT, Rowley HA, Hart RG, et al. Cerebral hemorrhage after intra-arterial thrombolysis for ischemic stroke: the PROACT II trial. Neurology. 2001;57:1603-1610.
79. Marzan AS, Hungerbuhler HJ, Studer A, Baumgartner RW, Georgiadis D. Feasibility and safety of norepinephrine-induced arterial hypertension in acute ischemic stroke. Neurology. 2004;62:1193-1195.
80. Copen WA, Rezai Gharai L, Barak ER, Schwamm LH, Wu O, Kamalian S, et al. Existence of the diffusion-perfusion mismatch within 24 hours after onset of acute stroke: dependence on proximal arterial occlusion. Radiology. 2009;250:878-886.
81. Hacke W, Albers G, Al-Rawi Y, Bogousslavsky J, Davalos A, Eliasziw M, et al. The Desmoteplase in Acute Ischemic Stroke Trial (DIAS): a phase II MRI-based 9-hour window acute stroke thrombolysis trial with intravenous desmoteplase. Stroke. 2005;36:66-73.
82. Larrue V, von Kummer RR, Muller A, Bluhmki E. Risk factors for severe hemorrhagic transformation in ischemic stroke patients treated with recombinant tissue plasminogen activator: a secondary analysis of the European-Australasian Acute Stroke Study (ECASS II). Stroke. 2001;32:438-441.
83. Clark WM, Wissman S, Albers GW, Jhamandas JH, Madden KP, Hamilton S. Recombinant tissue-type plasminogen activator (Alteplase) for ischemic stroke 3 to 5 hours after symptom onset. The ATLANTIS Study: a randomized controlled trial. Alteplase Thrombolysis for Acute Noninterventional Therapy in Ischemic Stroke. JAMA. 1999;282:2019-2026.
84. Aviv RI, d'Esterre CD, Murphy BD, Hopyan JJ, Buck B, Mallia G, et al. Hemorrhagic transformation of ischemic stroke: prediction with CT perfusion. Radiology. 2009;250:867-877.
85. Kidwell CS, Chalela JA, Saver JL, Starkman S, Hill MD, Demchuk AM, et al. Comparison of MRI and CT for detection of acute intracerebral hemorrhage. JAMA. 2004 20;292:1823-1830.
86. Ouriel K, Kandarpa K. Safety of thrombolytic therapy with urokinase or recombinant tissue plasminogen activator for peripheral arterial occlusion: a comprehensive compilation of published work. J Endovasc Ther. 2004;11:436-446.
87. King S, Khatri P, Carrozella J, Spilker J, Broderick J, Hill M, et al. Anterior cerebral artery emboli in combined intravenous and intra-arterial rtPA treatment of acute ischemic stroke in the IMS I and II trials. AJNR Am J Neuroradiol. 2007;28:1890-1894.
88. Brekenfeld C, Schroth G, El-Koussy M, Nedeltchev K, Reinert M, Slotboom J, et al. Mechanical thromboembolectomy for acute ischemic stroke: comparison of the catch thrombectomy device and the Merci Retriever in vivo. Stroke. 2008;39:1213-1219.
89. Gralla J, Schroth G, Remonda L, Nedeltchev K, Slotboom J, Brekenfeld C. Mechanical thrombectomy for acute ischemic stroke: thrombus-device interaction, efficiency, and complications in vivo. Stroke. 2006;37:3019-3024.
90. Combined intravenous and intra-arterial recanalization for acute ischemic stroke: the Interventional Management of Stroke Study. Stroke. 2004;35:904-9011.
91. Berlis A, Lutsep H, Barnwell S, Norbash A, Wechsler L, Jungreis CA, et al. Mechanical thrombolysis in acute ischemic stroke with endovascular photoacoustic recanalization. Stroke. 2004;35:1112-1116.

92. Nogueira RG, Smith WS. Safety and efficacy of endovascular thrombectomy in patients with abnormal hemostasis: pooled analysis of the MERCI and multi MERCI trials. Stroke. 2009;40:516-22.
93. Fader T, Gunzburger LK, Hartmann J, Chase R, Christie B, Meyer P, et al. Implementing meaningful CME as an essential component in a community hospital quality assurance plan. J Contin Educ Health Prof. 1988;8:231-237.
94. Cleves MA, Weiner JP, Cohen W, Athon C, Banks N, Boress L, et al. Assessing HCFA's Health Care Quality Improvement Program. Jt Comm J Qual Improv. 1997 Oct;23(10):550-60.
95. Kremer BK. Physician recertification and outcomes assessment. Eval Health Prof. 1991;14:187-200.
96. Pelletier LR, Tackett S. The performance measurement coordinating council: a town meeting. J Healthc Qual. 2000;22:24-31.
97. Hernandez AM. Trends in health care practitioner credentialing. J Health Care Finance. 1998;24:66-70.
98. Skolnick AA. JCAHO, NCQA, and AMAP establish council to coordinate health care performance measurement. Joint Commission on Accreditation of Healthcare Organizations, National Committee for Quality Assurance, American Medical Accreditation Program. JAMA. 1998;279:1769-1770.
99. Alberts MJ, Hademenos G, Latchaw RE, Jagoda A, Marler JR, Mayberg MR, et al. Recommendations for the establishment of primary stroke centers. Brain Attack Coalition. JAMA. 2000;283:3102-3109.
100. Alberts MJ, Latchaw RE, Selman WR, Shephard T, Hadley MN, Brass LM, et al. Recommendations for comprehensive stroke centers: a consensus statement from the Brain Attack Coalition. Stroke. 2005;36:1597-1616.
101. Quality improvement guidelines for adult diagnostic neuroangiography. Cooperative study between the ASNR, ASITN, and the SCVIR. American Society of Neuroradiology. American Society of Interventional and Therapeutic Neuroradiology. Society of Cardiovascular and Interventional Radiology. AJNR Am J Neuroradiol. 2000;21:146-150.
102. Angioplasty standard of practice. Standards of Practice Committee of the Society of Cardiovascular and Interventional Radiology. J Vasc Interv Radiol. 1992;3:269-271.
103. Levin DC, Becker GJ, Dorros G, Goldstone J, King SB, 3rd, Seeger JM, et al. Training standards for physicians performing peripheral angioplasty and other percutaneous peripheral vascular interventions. A statement for health professionals from the Special Writing Group of the Councils on Cardiovascular Radiology, Cardio-Thoracic and Vascular Surgery, and Clinical Cardiology, the American Heart Association. Circulation. 1992;86:1348-1350.
104. Spittell JA, Jr., Nanda NC, Creager MA, Ochsner JL, Dorros G, Wexler L, et al. Recommendations for peripheral transluminal angioplasty: training and facilities. American College of Cardiology Peripheral Vascular Disease Committee. J Am Coll Cardiol. 1993;21:546-548.
105. White RA, Hodgson KJ, Ahn SS, Hobson RW, 2nd, Veith FJ. Endovascular interventions training and credentialing for vascular surgeons. J Vasc Surg. 1999;29:177-186.
106. Standard for the performance of diagnostic cervicocerebral angiography in adults. Res. 5 - 1999. American College of Radiology Standards 2000-2001. Reston VA: American College of Radiology, 2000, pp. 415-426.
107. Standard for diagnostic arteriography in adults. Standards of Practice Committee of the Society of Cardiovascular and Interventional Radiology. J Vasc Interv Radiol. 1993;4:385-395.

108. ACC/AHA guidelines for cardiac catheterization and cardiac catheterization laboratories. American College of Cardiology/American Heart Association Ad Hoc Task Force on Cardiac Catheterization. J Am Coll Cardiol. 1991;18:1149-1182.
109. Standards for training in cardiac catheterization and angiography. Cathet Cardiovasc Diagn. 1980;6:345-348.
110. Friesinger GC, Adams DF, Bourassa MG, Carlson E, Elliott LP, Gessner IH, et al. Optimal resources for examination of the heart and lungs: cardiac catheterization and radiographic facilities. Examination of the Chest and Cardiovascular System Study Group. Circulation. 1983;68:891A-930A.
111. Conti CR, Faxon DP, Gruentzig A, Gunnar RM, Lesch M, Reeves TJ. 17th Bethesda conference: Adult cardiology training. Task Force III. Training in cardiac catheterization. J Am Coll Cardiol. 1986;7:1205-1206.
112. Hodgson JM, Tommaso CL, Watson RM, Weiner BH. Core curriculum for the training of adult invasive cardiologists: report of the Society for Cardiac Angiography and Interventions Committee on Training Standards. Cathet Cardiovasc Diagn. 1996;37:392-408.
113. Hirshfeld JW, Jr., Ellis SG, Faxon DP. Recommendations for the assessment and maintenance of proficiency in coronary interventional procedures: Statement of the American College of Cardiology. J Am Coll Cardiol. 1998;31:722-743.
114. Guidelines for percutaneous transluminal coronary angioplasty. A report of the American College of Cardiology/American Heart Association Task Force on Assessment of Diagnostic and Therapeutic Cardiovascular Procedures (Committee on Percutaneous Transluminal Coronary Angioplasty). J Am Coll Cardiol. 1993;22:2033-2054.
115. Weaver W, Myler RK, Sheldon WC, et al. Guidelines for physician performance of percutaneous transluminal coronary angioplasty. Cathet Cardiovasc Diagn. 1985;11:109-112.
116. Guidelines for the performance of percutaneous transluminal coronary angioplasty. Circulation. 1982;66:693-694.
117. Guidelines for percutaneous transluminal coronary angioplasty. A report of the American College of Cardiology/American Heart Association Task Force on Assessment of Diagnostic and Therapeutic Cardiovascular Procedures (Subcommittee on Percutaneous Transluminal Coronary Angioplasty). J Am Coll Cardiol. 1988;12:529-545.
118. Cowley MJ, Faxon DP, Holmes DR, Jr. Guidelines for training, credentialing, and maintenance of competence for the performance of coronary angioplasty: a report from the Interventional Cardiology Committee and the Training Program Standards Committee of the Society for Cardiac Angiography and Interventions. Cathet Cardiovasc Diagn. 1993;30:1-4.
119. Clinical competence in percutaneous transluminal coronary angioplasty. A statement for physicians from the ACP/ACC/AHA Task Force on Clinical Privileges in Cardiology. Circulation. 1990;81:2041-2046.
120. Gomez C, Kinkel P, Masdeu J, McKinney W, Polachini I, Jr., Tegeler C, et al. American Academy of Neurology guidelines for credentialing in neuroimaging. Report from the task force on updating guidelines for credentialing in neuroimaging. Neurology. 1997;49:1734-1737.
121. Bakshi R, Alexandrov AV, Gomez CR, Masdeu JC. Neuroimaging curriculum for neurology trainees: report from the Neuroimaging Section of the AAN. J Neuroimaging. 2003;13:215-217.
122. Higashida RT, Hopkins LN, Berenstein A, Halbach VV, Kerber C. Program requirements for residency/fellowship education in neuroendovascular surgery/interventional neuroradiology: a special report on graduate medical education. AJNR Am J Neuroradiol. 2000;21:1153-1159.

123. Beller GA, Bonow RO, Fuster V. ACC revised recommendations for training in adult cardiovascular medicine. Core Cardiology Training II (COCATS 2). (Revision of the 1995 COCATS training statement). J Am Coll Cardiol. 2002;39:1242-1246.
124. American Board of Internal Medicine Committee on Interventional Cardiology. Certificate of Added Qualifications in Interventional Cardiology. Available at: http://www.abim.org/exam/cert/icard.aspx. Accessed October 14, 2009.
125. Meyers, PM, Schumacher HC, Alexander MJ et al. Performance and training standards for endovascular ischemic stroke treatment. J NeuroInterv Surg. 2009;1:10-12.
126. ACGME Residency Review Committees - Program Requirements. Available at: http://acgme.org/acWebsite/navPages/nav_comPR.asp accessed August 23, 2009.
127. ACGME. Program Requirements for Residency Education in Neuroradiology. Available at: http://www.acgme.org/acWebsite/RRC_420/420_prIndex.asp. Accessed October 12, 2009.
128. ACGME. Program Requirements for Residency Education in Vascular Neurology. Available at: http://www.acgme.org/acWebsite/RRC_180/180?prIndex.asp. Accessed October 12, 2009.
129. ACGME. Program Requirements for Residency Education in Endovascular Surgical Neuroradiology. Available at: http://www.acgme.org/acWebsite/RRC_420/420_prIndex.asp. Accessed October 12, 2009.
130. ACGME. Program Requirements for Graduate Medical Education in Diagnostic Radiology. Available at: http://www.acgme.org/acWebsite/RRC_420/420/prIndex.asp. Accessed October 12, 2009.
131. Murray WB, Good ML, Gravenstein JS, van Oostrom JH, Brasfield WG. Learning about new anesthetics using a model driven, full human simulator. J Clin Monit Comput. 2002;17:293-300.
132. Schwid HA, Rooke GA, Carline J, Steadman RH, Murray WB, Olympio M, et al. Evaluation of anesthesia residents using mannequin-based simulation: a multiinstitutional study. Anesthesiology. 2002;97:1434-1444.
133. Watterson JD, Beiko DT, Kuan JK, Denstedt JD. Randomized prospective blinded study validating acquistion of ureteroscopy skills using computer based virtual reality endourological simulator. J Urol. 2002;168:1928-1932.
134. Rowe R, Cohen RA. An evaluation of a virtual reality airway simulator. Anesth Analg. 2002;95:62-66.
135. Forrest FC, Taylor MA, Postlethwaite K, Aspinall R. Use of a high-fidelity simulator to develop testing of the technical performance of novice anaesthetists. Br J Anaesth. 2002;88:338-344.
136. Byrne AJ, Greaves JD. Assessment instruments used during anaesthetic simulation: review of published studies. Br J Anaesth. 2001;86:445-450.
137. Issenberg SB, McGaghie WC, Hart IR, Mayer JW, Felner JM, Petrusa ER, et al. Simulation technology for health care professional skills training and assessment. JAMA. 1999;282:861-866.
138. Riley RH, Wilks DH, Freeman JA. Anaesthetists' attitudes towards an anaesthesia simulator. A comparative survey: U.S.A. and Australia. Anaesth Intensive Care. 1997;25:514-519.
139. Barr JD, Connors JJ, 3rd, Sacks D, Wojak JC, Becker GJ, Cardella JF, et al. Quality improvement guidelines for the performance of cervical carotid angioplasty and stent placement. Developed by a collaborative panel of the American Society of Interventional and Therapeutic

Neuroradiology, the American Society of Neuroradiology, and the Society of Interventional Radiology. J Vasc Interv Radiol. 2003;14:1079-1093.
140. INSTOR. Available at http://www.strokeregistry.org. Accessed October 12, 2009.
141. McGrath PD, Wennberg DE, Dickens JD, Jr., Siewers AE, Lucas FL, Malenka DJ, et al. Relation between operator and hospital volume and outcomes following percutaneous coronary interventions in the era of the coronary stent. JAMA. 2000 Dec;284:3139-3144.
142. Wennberg DE, Lucas FL, Birkmeyer JD, Bredenberg CE, Fisher ES. Variation in carotid endarterectomy mortality in the Medicare population: trial hospitals, volume, and patient characteristics. JAMA. 1998;279:1278-1281.
143. Hannan EL, Wu C, Ryan TJ, Bennett E, Culliford AT, Gold JP, et al. Do hospitals and surgeons with higher coronary artery bypass graft surgery volumes still have lower risk-adjusted mortality rates? Circulation. 2003;108:795-801.