# Training Guidelines for Intra-arterial Catheter-directed Treatment of Acute Ischemic Stroke: A Statement from a Special Writing Group of the Society of Interventional Radiology

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**Abbreviations:** ACC = American College of Cardiology, ACGME = Accreditation Council for Graduate Medical Education, ECASS = European Cooperative Acute Stroke Study, IA = intra-arterial, ICH = intracranial hemorrhage, IV = intravenous, MCA = middle cerebral artery, MELT = Middle cerebral artery Embolism Local fibrinolytic intervention Trial, MERCI = Mechanical Embolus Removal in Cerebral Ischemia [trial], mRS = modified Rankin Scale, NINDS = National Institute of Neurologic Disorders and Stroke, PROACT = Prolyse in Acute Cerebral Thromboembolism [trial], TPA = tissue plasminogen activator

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 facts that 10% of stroke victims die within 1 month and approximately one third die after living 6 months with severe disability render 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%–30% (4–6). Caplan et al (7) reported a 33% mortality rate in 3 months for main-trunk (ie, M1) MCA occlusive stroke, which decreased to 14.3% if there was only a distal branch occlusion (i.e., M3) (7).

Intravenous (IV) tissue plasminogen activator (TPA) has proven clinically beneficial (modified Rankin Scale [mRS] of 0–1 at 90 days) in only two trials: the National Institute of Neurologic Disorders and Stroke (NINDS) study part 2 (8), and the European Cooperative Acute Stroke Study (ECASS) III) (9). However, for the subset of patients with large vessel occlusion, IV TPA has been repeatedly demonstrated to be of limited clinical benefit (10–28). Large vessel occlusion can be documented by the hyperdense MCA sign on nonenhanced computed tomography (CT) or by intracerebral vascular imaging with CT angiography, magnetic resonance (MR) angiography, 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 study (32) showed good clinical outcomes (mRS 0–1 at 90 days), and IV TPA demonstrated no clinical benefit compared with placebo (17% good outcomes in NINDS study [32]; not fully reported for ECASS [31]). Concerning risks, treatment of patients with hyperdense MCA with IV TPA resulted in 11% symptomatic intracranial hemorrhage (ICH) in the NINDS study, compared with 2% for placebo (32). The largest database in the world for acute stroke cases treated with IV TPA is the Safe Implementation of Thrombolysis in Stroke-Monitoring Study database (33,34). In this database of 6,483 patients, it was demonstrated that 1,905 had the hyperdense MCA (29.3%), and of those, 16% had a favorable clinical outcome (mRS 0–1 at 90 days), in agreement with the NINDS study and ECASS. Large

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vessel occlusion (as confirmed by CT angiography, MR angiography, or catheter angiography) typically causes severe stroke, independently predicts poor neurologic outcome (25,30,35), and is a stronger predictor of neurologic deterioration than even early CT evidence of more than 50% MCA infarct (35). Similar to patients with the hyperdense MCA sign, poor clinical outcomes are associated with IV TPA treatment of image-confirmed large vessel occlusion. In a CT angiographic study (20), patients without occlusions but who were treated with IV TPA had no ICH, compared with a 23.3% (10% symptomatic) among those with large vessel occlusions ($P$ = .04). In the Diffusion and perfusion imaging Evaluation For Understanding Stroke Evolution study (36), cases of large vessel occlusion with a favorable mismatch as demonstrated by MR/MR angiography that were treated by IV TPA showed a 33% incidence of mRS of 0–2 at 30 days, with a 44% incidence of mRS scores of 0–2 among recanalized cases, versus 24% among those that were not recanalized (36). mRS 0–1 were not specifically reported in this trial (36). Notably, for those patients in the study in whom recanalization was achieved, 25% had symptomatic ICH, versus 6% of those who did not have recanalization (36). Patients with no MR angiographic occlusion had no symptomatic ICH (36), the same as demonstrated with no CT angiographic 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).

Although 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 Prolyse in Acute Cerebral Thromboembolism (PROACT) studies I (40) and II (41) and the MCA Embolism Local fibrinolytic intervention Trial (MELT) in Japan (42). In the double-blind randomized placebo-controlled PROACT II trial (41), 40% of treated patients had an mRS of 0–2 at 90 days, compared with 25% in the control group. MELT (42) affirmed the positive clinical benefit of IA lysis for MCA occlusion, demonstrating statistically significant improvement in excellent clinical outcome (mRS 0–2 at 90 days) in the IA urokinase group compared with the control group (42.1% vs 22.8%; $P$ = .045; odds ratio, 2.46; 95% CI, 1.09–5.54); 35% of patients who underwent IA lysis had nearly complete neurologic recovery (National Institutes of Health Stroke Scale of 0–1 at 90 days), versus 14% in the control group ($P$ = .017) (42). MELT (42) was prematurely halted as a result of approval of IV TPA in Japan for acute stroke, even though IV TPA has never been proven clinically beneficial in the specific group that was tested in the trial (ie, those with MCA occlusions), and thus the trial 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%; $P$ = .001). These positive clinical results are supported by multiple case series (10,27,37,46). The American Stroke Association (47), American Heart Association (48), and American College of Chest Physicians (49) guidelines now recommend IA revascularization for selected patients.

Estimates of potential candidates for IA revascularization range from 10,000 to 40,000 per year (50,51). These numbers are comparable to, or greater than, the number of patients with acute stroke currently being treated with IV TPA and will require more physicians that are trained to provide IA 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 neurologic examination and patient management, extensive microcatheter technical skill, and expertise in the interpretation of neuroimaging studies (eg, neuroangiography, CT, MR imaging, cerebral perfusion) to guide case analysis, treatment planning, intraprocedural decisions and catheter management, and postprocedural care. Specific training guidelines are necessary as a result of the wide variety of interested clinical specialties (many of which 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 neurologic deterioration and death related to the endovascular procedure itself are unacceptably high and can outweigh the potential benefits of cerebral revascularization. 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 prerequisites 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 neurologic pathophysiology, including the neurodiagnostic and pathologic possibilities encountered in acute ischemic stroke. Evaluating real-time procedural images when the vasculature is not completely visualized as a result of occlusion is necessary during the performance of the procedure and requires a high level of expertise.

The risk of permanent neurologic deficit as a result of diagnostic cerebral angiography ranges from 0.2% to 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 an incidence of permanent neurologic deficit or death of less than 0.2% (74–76). Patients with symptomatic atherosclerotic cerebrovascular disease (ie, ipsilateral transient ischemic attack or stroke) have a two to three times greater risk of stroke from diagnostic cerebral angiography (0.5%–5.7% risk of permanent deficit) compared with 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 angiography procedure, 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 interobserver variation are likely far higher when considering the more complex cerebrovascular anatomy. This is particularly true in situations in which major vascular landmarks are missing as a result of 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.

## 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 ICH in approximately 10% of treated patients, of which more than 50% will be fatal (78). Treatment of acute ischemic stroke requires superselective access of intracranial arteries that are occluded by clot (and thus frequently angiographically invisible), thereby creating the potential for inadvertent microvascular perforation with potentially fatal results. These selective microcatheterization tasks are particularly risky because 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. In addition, 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: (i) those that are the result of the primary insult that may not be fully understood, appreciated, or predictable; and (ii) those caused by operator technical errors or misjudgments. Some complications can be identified as being technical in nature, such as a large subarachnoid hemorrhage caused by a vascular perforation, or a visible air embolus (usually seen on follow-up CT). While there were no reported incidents of subarachnoid hemorrhage in the PROACT trials (40,41), cases of subarachnoid hemorrhage were reported in the Mechanical Embolus Removal in Cerebral Ischemia (MERCI) trial (43,44) and Penumbra trial (79), which used mechanical devices.

The first trials to study emergency endovascular stroke therapy were PROACT and PROACT II (80,81). Both the phase II PROACT and the randomized, placebo-controlled phase III PROACT II trials demonstrated statistically positive clinical benefit for the treatment of M1/M2 segment MCA occlusions. To maintain low operator complication rates, both trials mandated specific procedural detail that included not traversing the occlusion into unseen vascular territory. Symptomatic ICH occurred in 12 of the 110 patients (10.9%) treated with recombinant prourokinase and in two of the 64 (3.1%) who received IV heparin alone. Of the 12 patients treated with IA lytic agent who developed ICH, 10 died, resulting in a mortality rate of 83%. All of these hemorrhages occurred in the area of the acute infarct and showed a first onset of ICH-related symptoms at a mean of 10.2 hours ± 7.4 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 from hemorrhage at 90 days. However, there was one guide wire perforation and one case of air embolism.

The risk of symptomatic ICH after thrombolysis for acute ischemic stroke is substantial, regardless of whether the agent is infused by the IV or IA route. The rates of symptomatic ICH in IV TPA–treated patients were 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 study (83). In the presence of confirmed MCA occlusion (hyperdense MCA in the NINDS study [32]), the symptomatic ICH rate was 11% in the NINDS study with IV TPA (32), 10% in PROACT II with IA urokinase (41), and 9% (combined symptomatic and asymptomatic ICH) in MELT with IA urokinase (42).

The depth and duration of ischemia varies in all patients who experience 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 (eg, gingival and intestinal) (20,84,85). In peripheral arterial occlusions, systemic bleeding seems to be more common with IA use of tPA than with IA urokinase (86). The aforementioned factors may be related to severity of tissue damage or choice of lytic agent, but not necessarily technical factors.

Use or nonuse of a lytic agent does not necessarily solely determine the rates of hemorrhage, morbidity, or mortality. In the Interventional Management of Stroke studies I and II (87), clot was displaced into a previously uninvolved anterior cerebral artery in 1.7% of M1/M2 therapeutic procedures, and in three of 20 ICA T-type occlusions. Use of mechanical clot retrievers carries increased and unique risks such as vascular perforation (with high risk of mortality). With the use of thrombectomy devices, displacement of thrombotic material to a previously uninvolved territory (eg, 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 four cases), and frank subarachnoid hemorrhage was observed in at least five cases and was likely caused by vascular perforation (44). Symptomatic ICH occurred in 11 of 141 patients (7.8%), and five of 11 cases of bleeding were subarachnoid hemorrhages, indicative of the stress placed on these fragile intracranial vessels by the mechanical devices (44). Symptomatic ICH occurred at the same frequency in patients who had adjunctive lytic therapy as in those who received mechanical intervention alone. However, in patients whose occlusion was located in the MCA, the hemorrhage rate was only 6% (44), lower than in PROACT (40,41), with similar occlusion sites. Overall, 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% rate seen in the combined IV/IA lysis Interventional Management of Stroke study (90) and the 2.9% rate seen with endovascular photoacoustic recanalization (91). All these trials were performed by experienced and trained neurointerventionists. The overall mortality rate in the MERCI trial was 44% (44). In the pooled analysis of the MERCI and Multi MERCI trials (92), it was found that hemorrhage rates were 6% for recanalized cases but 16.7% for the nonrecanalized group. Hemorrhage rates were not affected by previous IV 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 endovascular stroke training. Therefore, appropriate and adequate cognitive and technical training, as well as sufficient clinical experience, are absolutely essential for the safe performance of these procedures.

## TRAINING

Official standards of training for all medical specialties have existed for more than a quarter century and 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 ACGME, the Federation of State Medical Boards of the United States, the American Board of Medical Specialties, and the National Board of Medical Examiners (53–55). Practicing within the appropriate scope of training is a fundamental rule of medical care. In addition, 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 credits (93–95). The Joint Commission 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 on 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, American College of Cardiology (ACC), Society of Vascular Surgery, Society of Interventional Radiology (SIR), American Society of Neuroradiology, and Society of NeuroInterventional Surgery (formerly the American Society of Interventional and Therapeutic Neuroradiology) (101–122). Guidelines from the American Heart Association, ACC, Society of Vascular Surgery, SIR, American Society of Neuroradiology, and Society of NeuroInterventional Surgery 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 laboratory 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 American Board of Medical Specialties 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 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 more than 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. Therefore, 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 pathophysiologic 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.

The present training document differs from earlier 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 substantiated 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.

Although dedicated training in vascular interventions must be the basis for endovascular stroke rescue, focused education and experience in the clinical care of a patient who has experienced a stroke and in specific procedural methods for stroke rescue should supplement that training and lead to better practice. A dedicated neurointerventional fellowship (Endovascular Surgical Neuroradiology) 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 IA 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 SIR during the 3 years after 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 who require 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 postgraduate 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 neurologic examination (including the National Institutes of Health Stroke Scale), clinical neurologic findings related to specific vascular ischemic insults, and neuroimaging of acute stroke by techniques such as CT, MRI, CT angiography, MR angiography, 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 IA 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 to achieve competency and to assure proper patient outcomes.

## EXISTING TRAINING 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 neurologic and neurovascular anatomy, neuropathophysiology, neurologic imaging, and clinical neurologic 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 MR imaging, transcranial Doppler imaging, cerebral angiography, CT angiography, MR angiography, CT and MR perfusion, positron emission tomography, single photon emission CT, and the evaluation of a broad range of neurologic conditions, including tumors, seizures, and other stroke mimics. These neurologic 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 are also required. Postresidency 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 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, Society of NeuroInterventional Surgery, American Society of Neuroradiology, and SIR (101,106). Recognizing that far greater numbers of cerebrovascular assessments are now routinely performed noninvasively with the use of CT angiography or MR angiography, and that there is now extensive exposure to these noninvasive angiograms in some specialties, the current recommendation from the American College of Radiology for credentialing for diagnostic cervicocerebral catheter angiography is 50 cases, supplemented by other general angiographic and noninvasive neurovascular imaging experience. Radiology, neuroradiology, and ACGME-approved Endovascular Surgical Neuroradiology training programs (that allow entry from only 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 neuroradiologic 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 angiography procedures before training in this neurointerventional specialty (122). This requirement is not altered by previous 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, the Society of Neuro-Interventional Surgery, American Academy of Neurology, Society of Vascular and Interventional Neurology, and American Association of Neurologic Surgeons/Congress of Neurological Surgeons require the same training as that necessary to perform the full spectrum of endovascular neurointerventions: 1 year of Endovascular Surgical Neuroradiology fellowship (125).

The authors of the present 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 arteriography procedures, 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). 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 angiography procedures. In addition, prerequisite knowledge includes interpretation of at least 200 cervicocerebral catheter angiograms, at least 50 CT angiographic examinations, 50 MR angiographic examinations, and 25 noninvasive cerebral perfusion studies (CT perfusion/MR perfusion/single photon emission CT). 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). 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 neurologic 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 (Core Cardiology Training Symposium 2), we emphasize that, in the absence of formal neuroscience training, industry-sponsored seminars, Continuing Medical Education coursework, and self-taught learning alone are insufficient for credentialing

**Table 1**
**Summary of Training Requirements**

| | |
|---|---|
| **Cognitive** | |
| 1. | Understanding of and certification in assessing the NIHSS |
| 2. | Six 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 examinations 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 compared with 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 pharmacologic agents used for acute stroke therapy |
| 11. | Understanding periprocedural and postprocedural hemodynamics and implications for appropriate patient care |
| **Brain Imaging** | |
| 12. | Interpretation of 200 CT and 50 CT angiograms |
| 13. | Interpretation of 200 MR images and 50 MR angiograms |
| 14. | Interpretation of 25 CT/MR perfusion |
| 15. | Interpretation of 200 cerebral arteriograms |
| **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 noncerebral |
| | b. 30 selective microcatheter procedures including 5 ICA/ECA |
| **Stroke** | |
| 18. | Five proctored cases |
| **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 |

Note.—ECA = external carotid artery; ICA = internal carotid artery; NIHSS = National Institutes of Health Stroke Scale; TIA = transient ischemic attack.

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 health care 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 stent placement (101,106,120,139), but are not yet available for endovascular treatment of acute ischemic stroke.

Because of the importance of continual assessment of performance, an interventional stroke therapy outcomes registry, preferably multiinstitutional 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 Interventional Stroke Therapy Outcomes Registry [140]) is required for all patients. This is useful for ongoing quality assurance/improvement as well as comparison versus outcomes from comparable facilities. Appropriate outcomes should be achieved during the training period and after granting of privileges 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 stent placement, coronary artery bypass grafting, carotid stent placement, and carotid endarterectomy indicate that, in general, greater experience confers better outcomes (141–143).

**Table 2**
**Physician and Facility Requirements for IA 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 administer the NIHSS.
2. A minimum of 6 months of formal neuroscience training is required that includes the study of stroke and its causes, clinical neurologic examination including the NIHSS, neuroanatomy, neuropathology, cerebrovascular anatomy and hemodynamics, and comprehensive neuroimaging (eg, CT, CT angiography, CT perfusion, multimodal MR, carotid and transcranial Doppler, nuclear SPECT, cerebral angiography, PET).
3. A dedicated CME stroke-specific educational course (see text) or GME curriculum is required and should also contain certain mandatory cognitive elements described below. The training in imaging interpretation (brain CT, MR, CT angiography, MR angiography, 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 MR, including conventional and diffusion-weighted sequences. Interpretation, reporting, and/or supervised review of 200 brain MR studies, including at least 50 cases with early signs of acute ischemic stroke with diffusion-weighted MR sequences.
   d. Ability to recognize stenotic, embolic, and thrombo-occlusive cerebrovascular lesions on catheter angiography, MR angiography, and CT angiography. Minimal training must include interpretation, reporting, and/or supervised review of 50 cerebral MR angiography and 50 CT angiography 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 cervicocerebrovascular 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 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 IA 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 (by IA or IV means), and antiplatelet agents. The ability to treat hypertension and other procedural or clinical complications potentially encountered in the acute setting is also 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 previous 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 arteriography with outcomes that must meet or exceed the benchmarks set by the 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***

(*Continued*)

**Table 2**
**Physician and Facility Requirements for IA Catheter-directed Treatment of Acute Ischemic Stroke (*Continued*)**

2. Previous experience using microcatheter/microwire (3 F or less) systems including performance of at least 30 interventional arterial cases using the selective placement of microcatheters and microwires into third-order or higher branches including at least 5 cases of selective ICA or ECA branch catheterization; ***and***
3. Performance of at least 5 catheter-directed intracranial stroke lysis cases with all cases as primary operator under the 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. This supervision may be in person or by teleradiology/telephone.

**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. Preexisting Credentials**

All physicians already credentialed to perform IA catheter-directed stroke procedures before 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, although 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 h per 2 y.
2. The physician should have procedure outcomes that are acceptable by institutional or national standards as indicated by participation in a national endovascular stroke therapy outcomes registry.
3. Outcomes performance
   a. Although 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-d outcomes be recorded and submitted to such registry to document adequate quality and satisfactory performance.

Note.—ACR = American College of Radiology; CME = Continuing Medical Education; ECA = external carotid artery; GME = Graduate Medical Education; ICA = internal carotid artery; NIHSS = National Institutes of Health Stroke Scale; PET = positron emission tomography; SPECT = single photon emission CT.

## SPECIFIC RECOMMENDATIONS REGARDING PHYSICIAN QUALIFICATIONS TO PERFORM IA CATHETER-DIRECTED TREATMENT OF ACUTE ISCHEMIC STROKE

Continuous clinical and procedural assessment, careful judgment, and crucial ongoing decision-making are fundamental parts of any surgical/endovascular interventional procedure, and therefore all 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 nonaccredited 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 neurointervention-specific technical skills as described later. Cognitive requirements should also be part of an intensive Continuing Medical Education or Graduate Medical Education course or training curriculum dedicated to catheter-directed stroke therapy, as described later and summarized in **Table 1**. Adequate training is documented by (i) passing a written examination to assess cognitive knowledge (see Appendix), (ii) direct observation of technical skills as listed in the Appendix and assessment of the ability to integrate cognitive and technical skills, (iii) being proctored for initial procedures with acceptable outcomes, and (iv) demonstrating satisfactory outcomes by submitting all cases to a national registry such as the Interventional Stroke Therapy Outcomes Registry (140).

A thorough description of physician and facility requirements for intra-arterial catheter directed treatment of acute ischemic stroke is provided in **Table 2**.

## 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-procedural neurocritical care of endovascularly treated stroke patients. There must be daily around-the-clock availability of neurosurgical care to treat possible complications of stroke therapy.

2. There must be an active quality assurance program for stroke therapy to monitor outcomes in the periprocedural period and at 90 days. All patients receiving emergency interventional stroke therapy must be routinely reviewed by the quality assurance program. Outcomes must be tracked and recorded. Submission of outcomes to a registry with national participation (140) is required.

## 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. In addition, 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 American Board of Medical Specialties, and all individual state medical licensing boards. Because of 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).

## APPENDIX: A: TEST CONTENT

### I. Patient Selection and Evaluation

### A. Imaging Competencies

1. Essential neuroanatomy
2. Brain CT and MR scan interpretation
   a. CT appearance of stroke and stroke mimics (eg, parenchymal hemorrhage, subdural or subarachnoid hemorrhage, mass lesions)
   b. MR appearance of stroke and stroke mimics (eg, white matter diseases, posterior reversible encephalopathy syndrome, venous thrombosis, inflammatory/infections processes)
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
   a. Knowledge of cerebrovascular anatomy
   b. Normal anatomic variants (eg, trigeminal artery)
   c. Circle of Willis variations
   d. Identification of superficial and deep watershed areas on cerebral angiography
   e. Ability to distinguish lesions likely to produce hypoperfusion and watershed vs embolic infarcts
   f. Expected values of flow rate of various vessels (ie, CCA, ICA, ECA, MCA, vertebral, basilar)
   g. Functional neuroangiography
      i. Variations in cervical and cerebral arterial trunk and branch development
      ii. Common pathways of collateral flow
      iii. "Dangerous" collateral vascular supply to intracranial vessels
      iv. 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 (eg, vessel perforation, vessel displacement, embolization, dissection, intracranial flow rate)

### B. Clinical Competencies

1. Knowledge of functional cerebral/cerebellar anatomy (recognition of functional Brodmann 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 examination, 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. Competence to assess the Modified Rankin Scale (mRS) with completion of course and test
5. Knowledge of clinical presentation of stroke mimics
6. Assessment of a conversion reaction
7. Knowledge of 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. Knowledge of risks and benefits of various therapies
   a. IV
   b. IV as bridge to IA
   c. IA
   d. 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. IA 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 guide wires with guide catheters
   e. Proper choice of placement of guide catheter 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 medium in the cerebral vasculature and/or past an occlusion
   q. Infusion techniques
      i. Anticoagulants
      ii. Lytic agents
      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 ICH
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. Lytic agents
    d. Heparin
    e. Diuretics
    f. Direct thrombin inhibitors
    g. Antiplatelet agents
    h. Blood transfusions
    i. Platelet transfusion
    j. Sedatives
    k. Fluid management
    l. Narcotics
11. Implementation of written protocols and order sets
    a. Preprocedure evaluation
    b. Postthrombolytic therapy management
    c. Management of hemorrhagic stroke
12. Risk factor management
    a. Timely workup 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

Note.— CCA = common carotid artery; ECA = external carotid artery; ICA = internal carotid artery; MCA = middle carotid artery; NIHSS = National Institutes of Health Stroke Scale; TIA = transient ischemic attack.

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