Society of Interventional Radiology Training Guidelines for Endovascular Stroke Treatment

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ABBREVIATIONS

ACGME = Accreditation Council for Graduate Medical Education, ACR = American College of Radiology, AIS = acute intervention for stroke, ASNR = American Society of Neuroradiology, CME = continuing medical education, DR = diagnostic radiology, EBNI = European Board of Neurointervention, EVT = endovascular thrombectomy, JC = Joint Commission, PCI = percutaneous coronary intervention, PSC = primary stroke center, SNIS = Society of NeuroInterventional Surgery

INTRODUCTION

In 2009, the Society of Interventional Radiology (SIR) published training guidelines for intraarterial catheter-directed treatment of acute ischemic stroke (1). At that time, catheter-directed thrombolysis was the dominant endovascular therapy and the only such therapy studied in randomized trials (2,3). Only first-generation mechanical thrombectomy devices were available. Computed tomographic (CT) angiography, magnetic resonance (MR) angiography, and perfusion imaging were not routinely used for assessment of large-vessel occlusion and/or parenchymal infarction and ischemia. Since 2009, multiple randomized trials and meta-analyses have confirmed the safety and effectiveness of intraarterial catheter-directed treatment of acute ischemic stroke with the use of current-generation mechanical thrombectomy devices for emergent large-vessel occlusion stroke (4–19). Based on multiple recent randomized controlled trials, endovascular thrombectomy (EVT) has become the standard of care, where available, for emergent large-vessel occlusion and is recommended for use with level IA evidence by American and international stroke organizations (20–24). Benchmarks for quality outcomes have been established (25), along with higher-level stroke center designation by accrediting bodies including comprehensive stroke centers and, more recently, thrombectomy-capable stroke centers. EVT is also being performed in many primary stroke centers (PSCs) (26). Given the extensive changes since 2009 in endovascular stroke care, revision of the 2009 SIR training guidelines is timely and necessary.

DOCUMENT DEVELOPMENT PROCESS

Writing Committee Organization

The writing committee consisted of 17 members across North America representing the SIR, identified because they had experience in (i) currently providing stroke care or (ii) developing training or education curricula. All members participated in composing the document and reviewing the content, and 15 of the members voted in Delphi rounds. To obtain diverse experience, the authors were drawn from academic and community settings with high and low volumes and have fellowship training in vascular/

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interventional radiology (IR), neurointerventional radiology, dual IR/neurointerventional radiology, neurosurgery, or vascular neurology.

Document Development and Approval

Level I evidence to support specific training guidelines is lacking. The guidance in the SIR training statements is based on available evidence, and, when evidence is absent, reflects expert opinion. Areas without unanimous consensus were voted on anonymously as established by the RAND methodology (27).

The writing group convened by conference calls and emails to draft and revise the document. The document was then reviewed by relevant SIR standards workgroups to ensure accuracy and a balanced perspective.

EVT TRAINING BACKGROUND

The IR physician is expected to have baseline mastery, in accordance with the Accreditation Council for Graduate Medical Education (ACGME) milestones of level 4 or higher, of arterial access, selective vascular catheterization including microcatheters, and mechanical revascularization including thrombectomy and thrombolysis of extracranial vessels (28). The IR physician is also expected, as part of core training and certification in diagnostic radiology (DR), to have experience with neuroimaging including CT, MR imaging, and perfusion imaging.

Interventional radiologists have been partners with neurointerventional radiologists, endovascular neurosurgeons, and interventional neurologists in acute intervention for stroke (AIS) since the inception of EVT. Vascular/IR physicians who were not trained in formal neurointerventional fellowships have historically provided and continue to provide EVT in substantial numbers with good outcomes, comparable to those achieved by neurointerventional physicians during similar years (29–35). A recent survey of the Joint Commission (JC) PSCs found that 60% of the responding PSCs performed EVT, and, of these, 41% relied on IR physicians to provide this care (26). Similarly, analysis of the Medicare database found that 34% of EVT cases were performed by physicians who were not trained in dedicated neurointerventional fellowships (36). In the landmark trial of Berkhemer et al (4), the majority of thrombectomies were performed by interventional radiologists (van Zwam W, written communication, July 23, 2018). These data support the important role of interventional radiologists in EVT for acute ischemic stroke.

Multiple societies involved in the care of patients with neurovascular diseases have published EVT training guidelines that require a formal neurointerventional fellowship or near-equivalent for new practitioners (37), conferring competency in the full spectrum of neuroendovascular interventions. A requirement for full-scope neuroendovascular training (Committee on Advanced Subspecialty Training or equivalent) as a basis for the performance of EVT has been considered by the JC in its comprehensive stroke center and thrombectomy-capable stroke center requirements (38), and is not a requirement for stroke centers certified by Det Norske Veritas (39) or the Healthcare Facilities Accreditation Program (40). However, the relatively high demand for physicians with competency in performance of stroke interventions nationwide, compared with the relatively low volume of other neuroendovascular interventions, creates a workforce challenge, particularly in communities outside of urban areas; this continues to create a demand for expertise from interventional radiologists who practice in these communities. The establishment of training guidelines to ensure competency standards that meet the needs of patients, hospitals, and physicians in these communities is relevant. It is intended that, by implementing and adhering to these training guidelines, the motivated diplomate in IR will be able to achieve competency to perform EVT with outcomes that meet published quality benchmarks (25) and are comparable to those of published registries and trials (4–10,16,17,19,35,41–48).

COGNITIVE AND TECHNICAL SKILLS

It is the consensus of this writing panel for IR stroke training that a fellowship in full-scope neuroendovascular interventions is not required to safely and effectively perform endovascular treatment of acute ischemic stroke; however, specific and rigorous training with demonstration of competencies is required.

A 2016 consensus statement from neurology, neuroradiology, and neurointerventional societies (37) recommended dedicated fellowship training in neurointerventional radiology for a preferred minimum of 1 year as baseline training and qualifications for new physicians performing endovascular ischemic stroke interventions. Similarly, the European Board of Neurointervention (EBNI) EVT stroke training guidelines recommend 1 year of training in clinical neurosciences and diagnostic neuroimaging followed by 1 year of training in acute ischemic stroke interventions. Allowances were made for physicians already performing stroke interventions, and, specifically, the EBNI guidance document (49), section 2.2, states that, "depending on previous training, the training time may be reduced as credit is given for previous training and clinical skills. The assessment of previous training and clinical skills and evaluation of remaining training time is the responsibility of the … program after a thorough and careful assessment of documented and proven training and experience" (49).

The present document focuses on acquisition of knowledge with subsequent mastery validated by review by a competent and experienced trainer or proctor. This knowledge- and skill-based approach is similar to that adopted by the EBNI (49) and other societies (37). Because the effectiveness of these training guidelines are to be assessed by outcomes measurement, it is required that outcomes be tracked for the purposes of documenting acceptable performance relative to previously published trials and national benchmarks (25). The authors strongly suggest participation in a national registry to allow outcomes to be benchmarked against other participating facilities.

It is recognized that there are at least 3 components of adequate training for competency to perform endovascular interventional procedures for acute ischemic stroke:

1) Formal training that imparts the required depth of cognitive knowledge of the brain and its associated pathophysiologic vascular processes, clinical syndromes, the full array of ischemic stroke presentations, and pre-, peri-, and postprocedural care;
2) Procedural skill, including management of complications secondary to endovascular procedures, that is achieved by supervised training 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 an adequate number of diagnostic and interventional/endovascular procedures with proper tutelage.

Cognitive Skills

The consensus of the authors is that a minimum of 6 months of documented cognitive neuroscience training during or after residency is necessary to become competent in the interventional care of patients with acute ischemic stroke. For those physicians entering an IR/DR residency, the 6 months includes diagnostic neuroradiology, interventional neuroradiology, and care of neurosciences patients with at least 3 months' experience in neurology, neurosurgery, and/or neurocritical care. For those physicians who have completed residency and are not currently performing EVT, training occurs with a proctor and with postgraduate educational courses. For those physicians who have completed residency and are already performing EVT and caring for patients with ischemic stroke, the physician must continue annual stroke education and have outcomes that meet quality benchmarks (25). The cognitive training is listed in outline form as a curriculum in **Appendix A**.

Technical Skills

Competence in cervicocerebral diagnostic angiography is mandatory for the performance of neurointerventional endovascular procedures. The 2016 update of the American College of Radiology (ACR)/American Society of Neuroradiology (ASNR)/SIR/Society of NeuroInterventional Surgery (SNIS) Practice Parameter for the Performance of Diagnostic Cerebral

Table 1. Summary of Training Requirements

Cognitive

1. Understanding of and certification in assessing the National Institutes of Health Stroke Scale.
2. 6 months of documented neuroscience training relevant to acute ischemic stroke and related neurovascular disorders and mimics.
3. Stroke specific training in clinical presentation of stroke and associated vascular territories.
4. Stroke specific examinations for stroke mimics and psychiatric disorders.
5. Ability to evaluate imaging criteria for appropriate patient selection for acute stroke treatment.
6. Ability to differentiate acute ischemic lesions as compared with chronic lesions and/or tumors, etc.
7. Ability to recognize etiology of transient ischemic attack and acute stroke, including stenosis and embolus.
8. Knowledge of cerebrovascular hemodynamics as it relates to perfusion imaging and clinical presentation.
9. Knowledge of pharmacologic agents used for acute stroke therapy.
10. Management of periprocedural complications.
11. Understanding pre-/peri-/postprocedural hemodynamics and implications for appropriate patient care.
12. Observation of a minimum of 20 cerebrovascular thrombectomy procedures.

Cervicocerebral Imaging (This knowledge base can be acquired during routine Accreditation Council for Graduate Medical Education training or in postgraduate dedicated stroke training, including cases from teaching files)

1. Interpretation of 200 CT scans and 50 CT angiograms
2. Interpretation of 200 MR imaging scans and 50 MR angiograms
3. Interpretation of 25 CT/MR perfusion examinations
4. Interpretation of 200 catheter cervicocerebral angiograms

Procedural Experience

1. 200 selective vascular catheterizations including:
   a. 50 cervicocerebral angiography procedures
   b. 100 superselective microcatheter angiograms
2. 10 procedures in the head and neck
3. 10 carotid bifurcation revascularization procedures
4. 30 cerebrovascular thrombectomy procedures

Angiography (50) recommends a minimum of 50 diagnostic cerebral angiograms to establish competency. This training can be obtained during or after completion of an ACGME-approved DR or IR residency. The ACGME recommends a minimum of 100 diagnostic cerebral angiograms before beginning fellowship training in interventional neuroradiology (Endovascular Surgical Neuroradiology) (51). The Committee on Advanced Subspecialty Training requirements include at least 200 diagnostic and/or interventional cerebral angiograms before beginning neuroendovascular fellowship (52).

For fellowship- or IR residency–trained IR physicians who wish to treat acute ischemic stroke with catheter-directed revascularization, the prerequisite physician training in cerebrovascular anatomy, catheterization, and hemodynamics should include at least 200 selective vascular catheterizations (second-order branch), 50 cervicocerebral angiography procedures, and 100 superselective (third-order or higher branch) microcatheter angiograms, of which 10 need to be in the head and neck. The microcatheter cases can be acquired during the selective vascular catheterization procedures and be counted toward both the selective and superselective catheterization requirements. The physician should perform a minimum of 10 carotid bifurcation revascularization procedures (eg, carotid stent, carotid balloon angioplasty, carotid thrombectomy, or crossing an occluded carotid artery on the way to the intracranial circulation). Stroke-specific training includes performing a minimum of 30 cerebrovascular stroke thrombectomies. All of these procedures are as primary operator. The training requirements are summarized in **Tables 1** and **2**.

TRAINING PATHWAYS

To achieve outcomes that meet international benchmarks in endovascular stroke treatment, structured training and education for cognitive and technical skills are required for those physicians performing the procedure. Focused training for endovascular stroke treatment can be achieved through multiple avenues.

IR/DR Residency

In this new 5-year ACGME-accredited program, in addition to 1 year of internship (total 6 y), trainees will have at least 2 years of dedicated clinical and procedural training (53). In a categoric 6-year pathway, motivated residents could have as much as 6 months of neuroscience training consisting of diagnostic neuroradiology, diagnostic/interventional neuroangiography, neurosurgery, stroke neurology, and neurocritical care in order to provide the disease-specific knowledge, clinical decision-making, and cerebrovascular catheterization experience that is necessary to become competent in stroke intervention.

Proctorship

For practicing interventional radiologists, who are no longer a part of formal training programs, additional training under the direction of qualified physicians in the form of proctorship can provide added knowledge and skill to achieve safety, confidence, and effectiveness in stroke intervention. Several studies have shown the effectiveness of this model for learning new procedures, especially in the surgical literature (54,55). Direct and indirect methods of supervised training are available for the interventionalist. Direct training would include hands-on participation in cases, whereas indirect training would include observing cases being performed.

Ideally, supervised training would include robust, hands-on training, not limited to interventional techniques but also workup before and management after thrombectomy. This method is preferred as it also allows one to more seamlessly integrate into the institution's own multidisciplinary stroke care team, which is beneficial to provide a smooth transition and promotes early collaboration.

A second option would be for the interventional radiologist to train at another institution. A full-time-equivalent commitment is recommended because of the unpredictable case rate for stroke care, and the time spent would be commensurate to the physician's core knowledge.

Another possible proctoring mechanism includes the engagement of a traveling consultant. Through this mechanism, an experienced physician travels to an institution to provide hands-on training. Traveling proctors have already been used in other areas of practice (56).

Proctors are expected to meet the following requirements:

- Certified Diplomate in good standing of the American Board of Radiology, American Board of Neurological Surgery, or American Board of Psychiatry and Neurology or equivalent;

Table 2. Training Requirements by Level of Experience

Recent IR fellows or IR/DR residents

- Graduation from an ACGME-accredited IR/DR residency program or completion of an independent IR residency
- Board-eligible for IR/DR certification or IR/DR board-certified
- 6 months of neurosciences training including diagnostic neuroradiology, interventional neuroradiology, and care of neurosciences patients (eg, elective rotations in neurology, neurosurgery, or neurocritical care)
- Mastery of the listed cognitive skills
- National Institutes of Health Stroke Scale certification
- Observation of $\geq$ 20 cerebrovascular thrombectomy procedures
- Neuroimaging interpretation: 200 CT scans, 50 CT angiograms, 200 MR imaging scans, 50 MR angiograms, 25 CT/MR perfusion examinations, and 200 catheter cervicocerebral angiograms
- Technical performance: 200 selective vascular catheterizations (including 50 cervicocerebral angiograms, 100 superselective [third-order or higher branch] microcatheter angiograms, 10 procedures involving head and neck vascular beds, 10 carotid bifurcation revascularization procedures, and 30 cerebrovascular thrombectomy procedures

Practicing Interventional Radiologists

- Graduation from ACGME-accredited DR residency and IR fellowship program, IR/DR residency, or independent IR residency
- IR/DR board-certified or board-eligible
- 6 months of neurosciences training including diagnostic neuroradiology, interventional neuroradiology, and care of neurosciences patients (eg, elective rotations in neurology, neurosurgery, or neurocritical care)
- Mastery of the listed cognitive skills
- National Institutes of Health Stroke Scale certification
- Observation of $\geq$ 20 cerebrovascular thrombectomy procedures
- Neuroimaging interpretation: 200 CT scans, 50 CT angiograms, 200 MR imaging scans, 50 MR angiograms, 25 CT/MR perfusion examinations, and 200 catheter cervicocerebral angiograms
- Technical performance: 200 selective vascular catheterizations, including 50 cervicocerebral angiograms, 100 superselective microcatheter angiograms, 10 procedures involving head and neck vascular beds, 10 carotid bifurcation revascularization procedures, and 30 cerebrovascular thrombectomy procedures

ACGME = Accreditation Council for Graduate Medical Education; DR = diagnostic radiology.

- Current, active, valid, unrestricted, and unqualified license to practice medicine in at least 1 jurisdiction in the United States and in each jurisdiction in which they practice;
- Active hospital appointment with privileges to perform AIS;
- Documentation of extensive AIS experience and clinical practice (having performed at least 50 AIS cases as primary operator) with at least 2 years of practice data with outcomes meeting international standards (25); and
- Satisfaction of all other requirements for periodic recertification/maintenance of certification/continued certification in their primary and secondary specialties.

Proctors have the following responsibilities:

- The proctor must provide to the trainee a final evaluation verifying that the physician being proctored has the ability to practice competently and independently;
- Documentation of satisfactory completion of level 4 milestones for EVT as delineated in the Endovascular Surgical Neuroradiology Milestones (28) would satisfy this requirement; and
- Evaluations should be communicated to the trainee in a timely manner, with the final evaluation being part of the permanent record maintained by the institution.

Whether individuals gain their experience through local proctorship, exposure to an alternate institution, or a traveling proctor, there remains a requirement to ensure appropriate clinical training that can confirm appropriate numbers of cases have been performed and necessary knowledge acquired during the proctorship period.

Courses

In addition to firsthand experience with stroke interventions, there are numerous educational stroke courses available to supplement stroke training. Procedural simulators have already been widely established as a validated method for teaching technical aspects of various procedures. In the near future, virtual reality may also bridge the gap between other didactic courses and hands-on training. It is important to keep in mind that the courses and resources described here only serve as a supplement to one's training and should never be considered as a replacement for formal, direct experience.

MAINTENANCE OF PHYSICIAN COMPETENCE

IR physicians performing EVT must update their knowledge and maintain procedural and patient-care skills. Specialty societies and governing bodies have proposed procedural volume, continuing medical education (CME) hours, enrollment in outcomes monitoring, participation in local and/or national quality initiatives, and outcomes benchmarks as tools for maintenance of physician competence in EVT (25,37,57–60).

IR physicians should participate in quality-assurance and -improvement programs as part of maintenance of physician competence. The quality-assurance programs should review and monitor patient outcomes periprocedurally and at 90 days after the procedure on a regular basis. The IR physician and the program should ensure that quality outcomes measures are within the accepted published guidelines. The threshold rates for revascularization, time to revascularization, complications, and 90-day functional outcomes have been established by an international, multisociety, and multispecialty consensus (25) (**Table 3**). As noted in that document (25), until > 50 EVT cases per year are performed at a facility, all EVT cases should be reviewed in a multidisciplinary conference. All cases should be submitted to a registry.

CME is an important part of maintenance of physician competence. The 2016 international multisociety consensus training document (37) suggests 16 hours of CME over a 2-year period dedicated to stroke-specific education. The ACR/ASNR/SIR/SNIS recommendations (57) do not specifically suggest stroke-specific CME but require adherence to ACR Practice Parameters for CME. The consensus in the present document is that IR physicians should earn a minimum of 16 hours of stroke-specific CME hours every 2 years to maintain competence.

Procedural specialties have proposed procedural volumes as a metric for maintenance of physician competence, yet have struggled to determine

Table 3. Endovascular Therapy Quality Improvement Case Review Triggers and Process Metrics (25)

Indications for Endovascular Treatment
- Metric 1: At least 90% of patients who meet the institution selection criteria (indications/contraindications) should be treated with endovascular therapy.

Data Collection
- Metric 2: 100% of patients have the required minimum process and outcomes data entered into an institutional or national database, trial, or registry.

Key Time Intervals

Door to imaging
- Metric 3: 75% of patients being evaluated for revascularization should have imaging initiated within 30 minutes from time of arrival. At the best of centers with high volumes and an established resource infrastructure, this is expected to be achieved in 12 minutes.

Imaging to puncture
- Metric 4: 75% of patients treated with endovascular therapy should have an imaging-to-puncture time of 110 minutes or less. At the best of centers with high volumes and an established resource infrastructure, this is expected to be achieved in 50 minutes or less.
- Metric 5: For patients transferred from another site and in whom imaging is not repeated, 75% of patients being treated should have a door-to-puncture time of 80 minutes or less.

Puncture to revascularization
- Metric 6: In 70% of patients, mTICI score $\geq$ 2b should be reached ideally within 60 minutes of arterial puncture.

Outcome Metrics

Recanalization/reperfusion
- Metric 7: The mTICI scale should be the primary scale used to assess angiographic reperfusion.
- Metric 8: At least 70% of patients should have an mTICI score $\geq$ 2b/3 ($>$ 50% reperfusion) for all clot locations.

Postprocedure CT/MR Imaging
- Metric 9: At least 90% of patients should have a brain CT or MR imaging within 36 hours of the end of the procedure.

SICH
- Metric 10: 100% of cases with SICH are reviewed.
- Metric 11: No more than 10% of treated patients should develop SICH.

Embolization of new territory
- Metric 12: No more than 10% of patients should have embolization of new territory.

Death within 72 hours of treatment
- Metric 13: 100% of cases of death within 72 hours of the end of the procedure are reviewed.

Clinical Outcomes
- Metric 14: All treated patients have a documented NIHSS score at discharge. Attempts are made to contact and document a follow-up mRS score at 90 days (evaluated in person or via telephone) on all treated patients. At least 90% of treated patients have a documented 90-day mRS score.
- Metric 15: Of all treated patients, at least 30% are independent (ie, mRS score 0–2) at 90 days after treatment.

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mRS = modified Rankin scale; mTICI = modified thrombolysis in cerebral infarction; NIHSS = National Institutes of Health Stroke Scale; SICH = symptomatic intracranial hemorrhage.

minimal volume standards. Institutional volumes and patient outcomes related to percutaneous coronary interventions (PCIs) have the most data (61–70), but the results are mixed (61–68). The correlation between operator volume and in-hospital mortality is modest, and no clear minimum threshold has been determined to predict best outcome (70). For acute PCI, which may be a more relevant comparison to EVT, the data suggestive of correlation between operator volume and outcomes are even less clear. We are aware of only 2 studies that report a significant inverse relationship (71,72), and 1 study failed to show an inverse relationship between in-hospital mortality and operator volumes (64). In the 2013 American College of Cardiology Foundation/American Heart Association/Society for Cardiovascular Angiography and Interventions PCI Update of the Clinical Competence Statement on Coronary Artery Procedures (73) and the 2018 European Society of Cardiology/European Association of Cardiac and Thoracic Surgery guidelines on myocardial revascularization (74), the weakening of the inverse relationship between volumes and outcomes was acknowledged, the supporting evidence was downgraded to level C, and a caution against preoccupation with specific volume recommendations was issued (73).

In EVT, the relationship between facility volume and outcomes data has been reported (75); however, data on individual volumes are lacking. The 2018 ACR/ASNR/SIR/SNIS practice parameters for EVT (57) and the 2016 Training Guidelines for Endovascular Ischemic Intervention international multisociety consensus document (37) did not include operator numbers for maintenance of physician competence but recommended assurance that outcomes meet acceptable thresholds. In 2018 and 2019, international neurointerventional consensus documents and the JC recommended that each operator maintain 15 procedures per year or 30 over a period of 24 months (38,59,76). With consideration of available data, the consensus in this document is that a minimum of 10 procedures per year for each operator is recommended for maintenance of physician competence. Certification as a center of excellence may require higher volumes. However, similar to the recommendations for acute PCI, operator volumes should not substitute for detailed quality and outcomes analyses (73), and, should an operator fail to meet the minimum procedure volume in a given year, a local institutional review of the operator's outcomes in AIS management should inform the decision on whether to continue or limit privileges.

INSTITUTIONAL INFRASTRUCTURE AND SUPPORT

Although the present document is directed at physician qualifications for performing EVT procedures, it should be emphasized that the clinical success of AIS is heavily dependent on the overall facility processes of care. Requirements and recommendations for infrastructure have been published by accrediting organizations (39,40,60) and various societies (25,58,77). EVT should be performed in hospitals with dedicated stroke units with appropriate staffing and infrastructure.

The multidisciplinary stroke team is made up of some or all of the following: emergency medical services, emergency physicians, neurology, vascular neurology, DR, IR, interventional neuroradiology, neurosurgery, interventional neurology, intensivists, hospitalists, vascular surgery, cardiology, intensive care unit, rehabilitation physicians, and primary-care physicians. Best patient outcomes are achieved when the multidisciplinary stroke team members perform designated duties in an efficient manner with open and clear communication according to set institutional protocols. Institutions performing stroke intervention must establish quality-assurance programs to optimize processes and outcomes, and technical and clinical outcomes must be entered into a database or registry (25). Eight hours of CME annually is required for stroke nurses and for the core stroke team (60).

Public education about the signs and symptoms of stroke, with active participation from members of the stroke team, will build community support for a successful stroke program. The requirement by accrediting bodies in stroke care for stroke units to provide at least 2 public stroke educational activities per year increases the public awareness of the disease's etiology and treatment (78–82).

The hospital must provide sufficient support, staff, and resources for the delivery of high-quality and efficient care. Imaging and laboratory services must be available at all times and provide rapid results. Imaging capability should include CT or MR imaging, including angiography and perfusion. Emergency response protocols should be robust, and, for appropriately selected patients, the prompt administration of intravenous alteplase and/or transport to the catheter angiography service for EVT must be available. The interventional team must be able to respond and be in house (nurse, technologist, and physician) within 30 minutes. Anesthesia and neurosurgical services must be available at all times, and neurosurgical care must be achievable within 2 hours.

Stroke units with appropriate infrastructure and support have been able to improve patient outcomes compared with general units, with reduced relative risk of death at 5 years, decreased institutional care, shorter lengths of stay, and higher likelihood of living at home with a better quality of life (78–82).

CONCLUSIONS

Endovascular ischemic stroke interventions are now the standard of care. Physicians with varying specialty backgrounds and training are providing this care. The present document describes the SIR recommendations for cognitive, clinical, and technical training for interventional radiologists to achieve appropriate outcomes.

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APPENDIX A. COGNITIVE SKILLS CURRICULUM

I. **Patient Selection and Evaluation**

A. Imaging competencies

- a. Essential neuroanatomy, including variants
- b. Brain computed tomography (CT) and magnetic resonance (MR) scan interpretation
  - i. CT appearance of stroke (Alberta Stroke Program Early CT Score and stroke mimics, eg, parenchymal hemorrhage, subdural or subarachnoid hemorrhage, mass lesions)
  - ii. MR appearance of stroke and stroke mimics (eg, white matter diseases, posterior reversible encephalopathy syndrome, venous thrombosis, inflammatory/infections processes)
  - iii. Imaging of hemorrhagic transformation
- c. Cervicocerebral CT angiogram interpretation
- d. Cervicocerebral MR angiogram interpretation
- e. Ability to distinguish ischemic penumbra from completed infarction with functional imaging
  - i. Brain CT perfusion scan interpretation
  - ii. Brain MR perfusion and diffusion scan interpretation
- f. Angiographic imaging
  - i. Knowledge of cerebrovascular anatomy
  - ii. Normal anatomic variants (eg, trigeminal artery, circle of Willis variations)
  - iii. Identification of superficial and deep watershed areas on all modalities of cerebrovascular imaging
  - iv. Ability to distinguish lesions likely to produce hypoperfusion and watershed vs embolic infarcts
  - v. Expected values of flow rates for contrast agent injection of various arteries (ie, common/internal/external carotid, middle cerebral, vertebral, basilar)
  - vi. Catheter neuroangiography:
    1. Variations in cervical and cerebral arterial trunk and branch development
    2. “Dangerous” collateral vascular supply to intracranial vessels
    3. Assessment of pathways and adequacy of collateral flow beyond vascular occlusions
    4. Relationship of angiographic abnormalities to clinical abnormalities
    5. Assessment of treatment strategies for angiographically demonstrated lesions related to potential for improving clinical outcome of stroke
    6. Ability to recognize complications of endovascular ischemic stroke treatment by changes in angiographic appearance (eg, vessel perforation, vessel displacement, embolization, dissection, intracranial flow rate)
    7. Revascularization scoring systems such as modified Thrombolysis In Cerebral Infarction

B. Clinical competencies

- a. 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)
- b. Knowledge of stroke syndromes associated with various vascular occlusions, including ability to distinguish cortical from subcortical or lacunar infarcts or posterior circulation infarcts affecting the brain stem and cerebellum
- c. Prehospital stroke scoring assessment tools
- d. National Institutes of Health Stroke Scale (NIHSS) evaluation
  - i. Competence to perform the NIHSS (completion of NIHSS course and test)
  - ii. Implications of various NIHSS scores
    1. Estimation of occlusion location
    2. Likelihood of large- vs small-vessel occlusion
    3. Importance of NIHSS score in the dominant vs nondominant hemisphere

e. Modified Rankin score: competence to perform modified Rankin score
f. Clinical presentation of stroke mimics, including psychiatric disorders
g. Natural history of stroke based on prior trials as stratified by risk factors
h. Assessment of current evidence-based literature with regard to the risk/benefit of stroke intervention based on age, NIHSS score, blood glucose, size of lesion on CT or MR, duration of symptoms, clot location, collateral flow, ischemic penumbra, etc.
i. Ability to explain risks and benefits of various therapies based on outcomes from endovascular and intravenous thrombolytic trials

II. **Clinical Management**

A. Assessment of patient risk of potential airway compromise and establishment of strategies for management
B. Management of blood pressure pre-/peri-/postprocedure
a. Acceptable ranges of blood pressure
i. Residual occlusion
ii. No residual occlusion
b. Knowledge of hyperperfusion syndromes
C. Management of coagulopathy
D. Knowledge of pharmacologic agents (eg, use of antiplatelets, anticoagulants, reversal agents, vasopressors, antihypertensives, diuretics, blood transfusion, sedatives, narcotics, fluid management, intracranial thrombolytic drugs)
E. Proper technique for preparing and administering pharmacologic agents for use in acute stroke therapy
F. Management of moderate sedation
G. Knowledge of treatment of procedural complications (eg, dissection, perforation, embolization to new territory, vasospasm)
H. Implementation of written protocols and order sets
a. Preprocedure evaluation
b. Post–endovascular thrombectomy management
c. Management of hemorrhagic complication of ischemic stroke
I. Risk factor management
a. Timely workup of transient ischemic attack
b. Primary differential considerations
c. Indications for longer-term anticoagulation and antiplatelet therapy

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