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Indications for Catheter-Based Angiography of the Cerebrovasculature

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Cerebral angiography has long remained the ''gold standard'' for the evaluation and diagnosis of cerebrovascular pathologic changes. Advances in interventional techniques and noninvasive imaging modalities have resulted in a transformation of the indications for catheter-based angiography. Most angiographic procedures are now performed with an intention to treat the underlying pathologic findings. Furthermore, imaging modalities like CT angiography (CTA) and magnetic resonance angiography (MRA) have supplanted catheter-based interventions for diagnosis because of their near-equivalent sensitivity and specificity as well as the associated reduced use of resources in terms of staffing, equipment, and cost. In this article, we review the current indications for catheter-based cerebral angiography for radiographic diagnosis, intraoperative decision making, initiation of endovascular therapy, and postprocedural monitoring.

Haschek and Lindenthal [1] and Moniz pioneered the development of cerebral angiography [2–4]. Luessenhop and Velasquez [5] subsequently validated the technique by exploring intracranial vessels with balloon-tipped catheters. Today, the process involves percutaneous entry into the femoral, radial, or brachial artery by use of a modified Seldinger technique [6]. The procedure is often performed on an elective basis; in light of competition from noninvasive studies, much scrutiny has been given to complication rates, efficacy, and cost.

Using the results of a cooperative study of the American Society of Interventional and Therapeutic Neuroradiology, American Society of Neuroradiology, and Society of Interventional Radiology, Citron et al [7] reported a neuroangiography success rate of 98%, as defined by an evaluation that adequately established or excluded pathologic findings of the extracranial or intracranial circulation, with a complication rate of 2.5% for reversible neurologic deficit and 1% for permanent neurologic deficit. Several studies have assessed the risk of thromboembolic events associated with diagnostic cerebral angiography in patients with cerebrovascular disease, subarachnoid hemorrhage (SAH), cerebral aneurysm, and arteriovenous malformation (AVM) [8–12]. The overall risk of thromboembolism-related complications occurring during or within 24 hours of the angiogram ranged from 1.0% to 2.6%. Permanent neurologic deficits occurred in 0.1% to 0.7% of cases. Complication rates in nonacademic settings are reported to be as low as 0.5% for stroke and 0.4% for transient ischemic attack [13]. Factors predisposing patients to increased risk of angiography-related complications include advanced age, severe atherosclerosis, symptomatic cerebrovascular disease, acute SAH, and vascular dysplasia [7]. Other factors that increase this risk include procedure length, number of catheter exchanges, catheter size, catheter manipulation, and amount of contrast media.

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Expense assumes greater importance with the advent of rising medical costs and limited reimbursement. Clinical studies increasingly take into account the cost of cerebrovascular imaging modalities. U-King-Im et al [14] evaluated MRA versus digital subtraction angiography (DSA) for carotid imaging, showing approximately a 2.4-fold increase in cost for DSA. Findings such as these prompt physicians to pay greater attention to preprocedural suspicion of the underlying pathologic changes as they evaluate cost-effectiveness and risk-benefit.

There are no absolute contraindications to catheter-based angiography. Relative contraindications include iodinated contrast media allergy, hypotension, severe hypertension, coagulopathy, renal insufficiency, and congestive heart failure. The possibility of contrast-induced nephropathy in patients with renal insufficiency remains the most common cause of avoiding angiography. A recent meta-analysis of seven randomized controlled trials reaffirms that hydration and *N*-acetylcysteine remain the treatment of choice to prevent contrast nephropathy in such patients, with an overall 56% reduction in the relative risk of developing nephropathy [15].

Atherosclerotic disease

Catheter-based angiography in cerebrovascular atherosclerotic disease may define occlusive morphology when CT or MRI techniques are of poor quality, equivocal, contraindicated, or inadequate. Angiography can better depict tandem lesions. The hemodynamic significance of a lesion can be determined by evidence of more than 50% reduction in luminal diameter, less than 2 mm of residual lumen, external carotid artery opacification preceding internal carotid artery (ICA) opacification, delayed ocular choroidal blush, or early opacification of the contralateral vasculature after ipsilateral dye injection [16]. Angiography is diagnostic and a means of immediate therapy. Current therapies include intra-arterial administration of thrombolytic agents, mechanical thrombolysis or thrombectomy, angioplasty, and stent placement.

Extracranial carotid stenosis has provided fertile ground for the comparison of imaging modalities. CTA, MRA, and ultrasonography (US) allow excellent visualization of the extracranial vasculature; however, many surgeons are reticent to perform surgery based on the findings of a single noninvasive study. MRA technology is notorious for overestimation of the severity of stenosis. In a study involving 91 patients with 70% to 99% stenosis by MRA evaluation, 19 patients had 50% to 69% stenosis and 5 patients had less than 50% stenosis by DSA [17]. Another study has shown a sensitivity and specificity of 95% and 90%, respectively, for identification of carotid stenosis greater than or equal to 70% with MRA as compared with DSA [18]. CTA has a reported 89% agreement with catheter-based angiography [19]. The collaborators of the North American Symptomatic Carotid Endarterectomy Trial concluded that transcranial Doppler (TCD) US was 59.3% sensitive and 80.4% specific for stenosis exceeding 70% [20]. More recently, sensitivities ranging from 81% to 93% in the anterior circulation, with a negative predictive value of 94%, have been reported [21].

DSA remains the method of choice for delineating occlusion versus trickle flow in near-occluded lesions of the ICA, although Chen et al [22] found a 100% correlation between DSA and CTA in differentiating total versus near occlusion in 57 patients. In light of a push toward noninvasive neuroimaging modalities for presurgical evaluation, a review panel sought to determine the most appropriate imaging studies to guide endarterectomy in 203 clinical settings of carotid artery disease [23]. As a result of their review, the panel recommended (1) conventional angiography or two concordant noninvasive studies (US, CTA, or MRA) in the setting of moderate symptomatic disease, (2) US plus another modality or MRA and CTA alone in the setting of severe asymptomatic disease, and (3) one noninvasive imaging study in the setting of severe symptomatic disease. When assessing patients, physicians must keep in mind that previous studies have reported a 6% to 7.9% misclassification of ICA stenosis, even when two noninvasive imaging strategies are combined [24,25]. The Warfarin-Aspirin Symptomatic Intracranial Disease (WASID) trial, which was recently funded by the National Institutes of Health, requires performance of angiography along with TCD US and MRA [26–28]. This trial provides an opportunity for critical evaluation of these noninvasive tests. The Stroke Outcomes and Neuroimaging of Intracranial Atherosclerosis trial is being conducted in collaboration with the WASID trial to define the TCD US and MRA parameters that determine severe (50%–99%) intracranial stenosis of large proximal arteries on catheter angiography [27].

DSA may help to guide intraoperative decision making. Aleksic et al [29] sought to determine whether DSA findings could predict the need for the placement of a shunt during carotid endarterectomy. A cross-flow toward the contralateral hemisphere noted during preoperative angiography had a sensitivity of 91% in obviating the need for intraoperative shunt placement during carotid surgery performed under local anesthesia. Further studies may delineate a positive predictive value for the necessity of a shunt.

Although new studies are ongoing to generate support for use of noninvasive imaging, DSA remains the modality of choice in the event of discordant noninvasive studies or when assessing patients for whom CEA would pose significant risk. A three-vessel angiogram remains the most effective method of determining the adequacy of collateral circulation.

Intracranial aneurysm

Cerebral aneurysms represent a focal dilation of an artery. The management and elimination of these lesions have gained much notoriety with the advent of approaches for endovascular repair. Spontaneous SAH demands immediate diagnostic angiography. DSA can provide a means to obtain the diagnosis and administer therapy. Questions remain with respect to the most appropriate initial study as well as the need for angiography after therapy or in the event of a nondiagnostic study, however. Another concerning topic involves the resolution of MRA and CTA in detecting aneurysms less than 5 mm in diameter. Rebleeding does not correlate with aneurysm size. Clinicians have to take this into account, because these smaller ruptured aneurysms may escape detection. Piotin et al [30] studied the volumetric assessment of intracranial aneurysms. Rotational DSA was more accurate than MRA or CTA, prompting these authors to recommend DSA for the evaluation of cerebral aneurysms.

The accuracy of MRA for detecting aneurysms larger than 3 mm approaches 90%; however, this falls to less than 40% for aneurysms smaller than 3 mm [16]. An early assessment of MRA for the screening of unruptured intracranial aneurysms in 200 patients revealed a 99.5% correlation between DSA and MRA; detection of a single 3-mm posterior communicating artery aneurysm was missed by MRA [31]. More recently, Watanabe et al [32] studied the ability of three-dimensional (3D) MRA to plan a surgical approach in 106 patients with SAH secondary to an intracranial aneurysm. Forty-six percent of patients had surgery on the basis of the MRA findings alone. The remaining patients required further imaging, consisting of CTA or DSA. Functional limitations of MRA included poor image quality (because of motion artifact), slow flow in the aneurysm, thrombosis, or subacute clot. Anatomy limited the proper surgical evaluation primarily in the following locations: basilar artery, ICA, or high-position anterior communicating artery. Blood flow is represented on MRA; therefore, turbulent flow may cause poor visualization, such as in the tortuous carotid siphon. Low perfusion, sluggish flow, or thrombus may obscure imaging, such as in giant aneurysms.

CTA has an accuracy of 90% when compared with DSA for depiction of aneurysms [33]. The advantage of CTA lies in its mechanism of distinguishing contrast flow from blood flow. CTA is even more sensitive than DSA in delineating the presence of contrast media, and it can differentiate the thrombus within a vessel. Although this makes CTA a useful adjunct for detecting the sluggish flow within giant aneurysms, bony artifact and acute blood can obscure the pathologic changes; thus, aneurysms in the cavernous sinus may be missed. In a recent report by Hoh et al [34], CTA was used as the sole imaging study for the prospective evaluation of 223 patients with intracranial aneurysms. Of these patients, 18% underwent a further pretreatment evaluation with DSA. All aneurysms responsible for the patients' presenting symptoms and 97% of multiple aneurysms were detected by CTA. Reasons for obtaining DSA after an initial evaluation with CTA included the necessity to clarify the relation of the aneurysm to the parent vessel or perforating branches or to assess further the morphology of the aneurysm and the anatomy of the aneurysm neck.

Yasui et al [35] conducted a study to delineate further the limitations of CTA as compared with DSA. CTA displayed a particular weakness in the evaluation of the posterior circulation. Perforators of the posterior cerebral artery, a small posterior communicating artery, and infundibular dilation of the posterior communicating artery could not be detected.

Infectious or mycotic aneurysms represent a subset of disease particularly suited to DSA evaluation. In a retrospective review, Venkatesh and colleagues [36] related a 90% incidence in the distal vasculature. All aneurysms were less than 10 mm, and most were 3 to 5 mm. Chun et al [37] recommend endovascular therapy in stable patients with ruptured infectious aneurysms, further supporting DSA as the imaging modality of choice.

Angiographically negative SAH remains another disease subset that is particularly suited to evaluation with DSA. Topcuoglu et al [38] conducted a retrospective review of patients with SAH without evident cause, concluding that noninvasive imaging with MRA and CTA provides little diagnostic value. Of those presenting with nonperimesencephalic SAH, only DSA elucidated a cause on follow-up evaluation.

Aneurysms are evaluated after coil embolization to assess for patency or residual neck and flow. Standard follow-up imaging often includes repeat DSA at 3, 12, and 36 months after the last embolization. Nome and colleagues [39] compared MRA and DSA in the follow-up evaluation of 51 patients treated with Guglielmi detachable coils (GDCs; Boston Scientific Target, Fremont, California). The sensitivity of MRA for detecting residual flow within the aneurysm was 97%. The patency status of parent artery and branch vessel flow was correctly identified in all but a single patient. The limitations of MRA included signal loss in the vicinity of the coil mass, reduced flow signal in adjacent vessels, and misinterpretation of high signal intensity from thrombus as circulating blood. Considering these deficiencies, DSA is recommended as the initial follow-up study, with a transition to MRA or CTA when these issues have been ruled out.

Cerebral vasculitis

The diagnosis of cerebral vasculitis represents a challenge to all clinicians. Inflammatory changes in the vessel result in narrowing and obliteration of the vascular lumen that can progress to thrombotic occlusion, necrosis, and rupture. Pathologic features of vasculitis include spasm, edema, cellular infiltration, and proliferation. Diagnosis is often beyond the resolution of conventional radiography, with the reported sensitivity of DSA being 24% to 33% [40,41]. Cloft et al [42] found a relatively poor correlation between MRA and DSA in the evaluation of patients with primary angiitis of the central nervous system, with MRA showing no pathologic features in 34% of abnormal territories. Although DSA is limited, it remains the standard of radiographic diagnosis.

Arteriovenous malformations and arteriovenous fistulas

AVMs are congenital anomalies of blood vessels that usually cause symptoms in the third or fourth decade of life. These lesions consist of dilated feeding arteries and a core or nidus of tangled vascular loops and terminate in draining veins. CT and MRI are excellent diagnostic adjuncts, although DSA is still considered the gold standard. Mori et al [43] reported rates of sensitivity and specificity of 87% and 100%, respectively, for MRA in diagnosing hemodynamic features of AVMs. Farb et al [44] found MRA to be equivalent to DSA for depiction of AVM components in 70% to 90% of cases. Aside from diagnosis, DSA may be useful in predicting hemorrhage. Using time-density curves obtained by DSA to elucidate hemodynamic risk factors for AVM hemorrhage, Todaka et al [45] showed a significant difference in the mean number of draining veins, the median transit time of the feeding artery, and the ratio of the mean transit time of the draining to the feeding vessels. DSA is also necessary for radiosurgical assessment. St. George et al [46] found that MRI localization of the AVM nidus before treatment was not predictable and that discrepancies with DSA findings were occasionally significant, thus precluding safe radiosurgical planning that relies on MRI as the sole imaging modality [46]. Concerning evaluation after treatment, empiric evidence supports initial DSA for immediate and initial postprocedure follow-up and MRA for long-term evaluation.

Arteriovenous fistulas represent an abnormal communication between high-pressure (arterial structures) and low-pressure (venous structures) systems. The vessels collateralize into a prominent network and are usually dural based. Although DSA remains the study of choice, with recent advances in endovascular treatment supporting this opinion, the diagnostic use of noninvasive imaging must be evaluated. Noguchi et al [47] attempted to define the diagnostic criteria on MRA by evaluating patients with angiographically proven moderate- to high-flow intracranial dural arteriovenous fistulas. Two blinded neuroradiologists evaluated the images. Sensitivity and specificity for the identification of multiple high-intensity structures adjacent to the sinus wall, high-intensity areas in the venous sinus, and early filling of the venous sinus were 100% and 100%, 76% and 86%, and 87% and 100%, respectively.

Intraoperative utility

As neurosurgeons gained familiarity with and appreciated the usefulness of DSA, a natural progression moved toward the application of this imaging modality for intraoperative evaluation. Early use of intraoperative angiography focused on the evaluation of surgically treated aneurysms. Studies show that angiography prompted a change in surgical treatment 7% to 14% of the time, resulting in a complication rate of 0% to 0.5% [48–50]. Tang et al [49] found that residual aneurysm and vessel compromise were the most common cause for a change in surgical strategy. In multivariate logistic regression analysis, location in the proximal ICA and size were the factors relating to the increased revision rates. Surgical procedures for the clipping of aneurysms in the superior hypophyseal artery and clinoidal region were fraught with the highest revision rates. Surgery for giant (>24 mm) and large (15–24 mm) aneurysms was revised in 29% and 22% of cases, respectively. Moreover, in a prospective assessment of intraoperative angiography during aneurysm surgery, Klopfenstein et al [48] found that experienced cerebrovascular surgeons could not predict the need for angiography. The group of patients labeled "intraoperative angiography unnecessary" before surgery had a surgical alteration rate equal to that for the "intraoperative angiography necessary" group. The most common causes for surgical revision in the group for whom intraoperative angiography was considered necessary were residual aneurysms and parent vessel occlusion, in addition to previously undiagnosed aneurysms. These findings prompted Klopfenstein et al [48] to recommend consideration of intraoperative angiography for most aneurysm cases.

Catheter-based angiography has been used to assess graft patency during extracranial-intracranial bypass procedures and has displayed branch occlusion in 7% to 16% of cases [50,51]. Using this approach to monitor graft patency, Yanaka et al [50] were able to open the occluded graft in all cases, resulting in a graft patency rate of 100% after surgery.

Concerning vascular malformations, a 10% to 36% incidence of residual AVM after surgery is reported in the literature [52–54]. Intraoperative adjuncts to improve resection rates would be of great benefit in reducing future hemorrhagic incidence or repeat surgery. When using intraoperative DSA during AVM resection, Lui et al [55] discovered abnormalities in 20% of patients. In one patient, angiographic imaging displayed residual AVM in the temporal lobe near a cortical draining vein and allowed for safe completion of the resection. In another patient, angiography documented abnormal displacement of the left posterior cerebral artery. A follow-up CT scan indicated an epidural hematoma effacing the left parietal area that required urgent surgical evacuation. In this case, the angiogram had provided a warning of an acute hemorrhagic event. For smaller AVMs, intraoperative DSA may be necessary simply to locate the nidus. These instances support the use of intraoperative angiography as a means to avoid further anesthesia or repeat craniotomy. Further study must decipher which procedures would best benefit from this adjunct.

Newer methods of arterial access are being developed to facilitate intraoperative angiography. Recently, Lee and Macdonald [51] described their experience with access via the superficial temporal artery. Fourteen percent of patients had unexpected findings, including arterial occlusion and residual aneurysm.

Assessing brain death

Those whose medical specialty involves the central nervous system are often called on to perform brain death examinations. Often, a bedside examination involving a detailed assessment of brain stem function, the interpretation of which is corroborated by at least two clinicians, suffices for the diagnosis of brain death. Confounding factors that may alter an examination include severe electrolyte, acid-base, or endocrine disturbances; the presence of severe hypothermia (defined as a core temperature of $\leq 32°C$); hypotension; and the absence of evidence of drug intoxication, poisoning, or neuromuscular blocking agents. In some European, South American, or Asian countries, routine confirmatory testing is required for the diagnosis of brain death. In the United States, such confirmation is optional in adults but recommended in children less than 1 year old [56]. Infants may not have fully developed cranial nerves, the findings of the examination may be difficult to interpret accurately, and the pediatric population has a tendency to become hypothermic when ill. On a neurosurgical service, a barbiturate-induced coma most often obviates an expedient diagnosis of brain death. When time becomes a factor (if organ donation is contemplated or examination findings are spurious), DSA can quickly provide a radiographic diagnosis of brain death. One should note absence of flow at the foramen magnum in the posterior circulation and at the petrosal portion of the carotid artery in the anterior circulation [57]. DSA may soon be supplanted by CTA in declaring brain death. Qureshi et al [58] reported CTA documentation of the absence of cerebral blood flow in patients receiving intravenous pentobarbital for burst suppression, thus allowing organ harvest or timely withdrawal of care. Further studies are necessary to evaluate the sensitivity and specificity of CTA versus DSA in brain death assessment.

Trauma

Blunt carotid injury is an uncommon but potentially devastating injury, with an incidence approaching 1% for all cases of blunt trauma injury [59]. Delayed symptoms complicate early diagnosis; thus, efforts have been made to devise a screening algorithm. Diagnostic studies are indicated in the face of hemorrhage of presumed carotid origin, cervical bruits, history of external cervical trauma with altered mental status, suspicious mechanism of injury, or lateralizing neurologic deficits unexplained by parenchymal damage [60]. Subtle vessel dissections and skull base anatomy present limitations for duplex scanning [61]. Regardless of its efficacy, MRA is often a logistic impossibility with trauma patients. Although CTA is becoming the favored diagnostic study, DSA remains the study of choice for the radiographic diagnosis of blunt carotid injury. When a liberalized screening method based on neurologic examination and mechanism of injury was used by Kerwin et al [62], 21 (44%) of 48 patients exhibited abnormal angiographic findings. Fracture through the foramen transversarium, unexplained hemiparesis, basilar skull fracture, unexplained neurologic examination results, and anisocoria revealed angiographic abnormalities in 60%, 44%, 42%, 38%, and 33% of patients, respectively, justifying the use of DSA in this patient population.

To evaluate noninvasive imaging in establishing a diagnosis of blunt cerebrovascular injury, Biffl et al [63] evaluated 62 trauma patients with a suspicious injury or examination by CTA or MRA. DSA was then used for comparison. Among patients with normal CTA results, 30% were found to have occult vascular injury by DSA, providing a sensitivity and specificity of 68% and 67%, respectively. Anatomic limitations secondary to bony artifact include the ICA in its petrous and cavernous segments and the vertebral artery within the vertebral foramina. Of those patients with normal MRA findings, 11% had a false-negative study, with a sensitivity and specificity of 75% and 67%, respectively. Aside from the logistic concerns, pseudoaneurysms presented difficulties for MRA assessment because of their turbulent flow. The findings led the authors to conclude that noninvasive imaging is not ready to replace DSA for the evaluation of trauma patients with suspected blunt cerebrovascular injury.

Summary

Catheter-based cerebral angiography remains an important method of garnering information about the cerebrovasculature. Although noninvasive imaging continues to supplant this gold standard, evidence-based medicine regarding the equivalence of these imaging modalities to DSA is lacking and studies need to be completed. When clinicians rely on a study to make surgical decisions, they must concede to the existing evidence when choosing the optimal method of diagnostic evaluation.

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