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John E Wanebo

john.wanebo@barrowbrainandspine.com

Sepideh Amin-Hanjani

Cynthia Boyd

Terry Peery

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Assessing Success after Cerebral Revascularization for Ischemia

John E. Wanebo, M.D.,¹ Sepideh Amin-Hanjani, M.D.,^{2,3} Cynthia Boyd, Ph.D.,⁴ and Terry Peery, M.D.⁵

ABSTRACT

Cerebral revascularization continues to evolve as an option in the setting of ischemia. The potential to favorably influence stroke risk and the natural history of cerebrovascular occlusive disease is being evaluated by the ongoing Carotid Occlusion Surgery Study and the Japanese Extracranial-Intracranial Bypass Trial. For those patients who undergo bypass in the setting of ischemia, four key areas of follow-up include functional neurological status, neurocognitive status, bypass patency, and status of cerebral blood flow and perfusion. Several stroke scales that can be used to assess functional status include the National Institutes of Health Stroke Scale, Barthel Index, Modified Rankin Scale, and Stroke Specific Quality of Life. Neurocognition can be checked using the Repeatable Battery for the Assessment of Neuropsychological Status, among other tests. Bypass patency is checked intraoperatively using various flow probes and postoperatively using magnetic resonance angiography (MRA) or computed tomographic angiography (CTA). Cerebral blood flow and perfusion can be assessed using a host of modalities that include positron emission tomography (PET), xenon CT, single photon emission computed tomography (SPECT), transcranial Doppler (TCD), CT, and MR. Paired blood flow studies after a cerebral vasodilatory stimulus using one of these modalities can determine the state of autoregulatory vasodilation (Stage 1 hemodynamic compromise). However, only PET with oxygen extraction fraction measurements can reliably assess for Stage 2 compromise (miserable perfusion). This article discusses the various clinical, neuropsychological, and radiographic techniques available to assess a patient's clinical state and cerebral blood flow before and after cerebral revascularization.

Skull Base, volume 15, number 3, 2005. Address for correspondence and reprint requests: John E. Wanebo, M.D., Department of Neurosciences, Division of Neurosurgery, Naval Medical Center San Diego, 34730 Bob Wilson Dr., Ste. 201, San Diego, CA 92134-3201. E-mail: JEWanebo@nmcscd.med.navy.mil. ¹Department of Neurosciences, Division of Neurosurgery, Naval Medical Center San Diego, San Diego, California; ²Division of Neurological Surgery, Barrow Neurological Institute, St. Joseph's Hospital and Medical Center, Phoenix, Arizona; ³Department of Neurosurgery, University of Illinois at Chicago, Chicago, Illinois; ⁴Department of Neurosciences, Defense Veterans' Brain Injury Center, Naval Medical Center San Diego, San Diego, California; ⁵Department of Neurosciences, Division of Neurology, Naval Medical Center San Diego, San Diego, California. Published by Thieme Medical Publishers, Inc., 333 Seventh Avenue, New York, NY 10001, USA. Tel: +1(212) 584-4662. DOI 10.1055/s-2005-872597. Published online August 17, 2005. 1531-5010,p;2005, 15,03,215,227,ftx,en;sbs00457x.

KEYWORDS: Stroke, cerebral revascularization, carotid occlusion, neurocognitive testing, cerebral blood flow, bypass patency

Cerebral revascularization continues to evolve as an option in the setting of cerebral ischemia. The primary indications for revascularization include patients with moyamoya syndrome and those with carotid occlusion and are addressed in other works. Although the Extracranial-Intracranial (EC-IC) Bypass Study published in 1985 demonstrated failure of bypass to significantly improve stroke risk over medical management, this study preceded effective cerebral blood flow (CBF) studies.¹ Currently, the potential use of superficial temporal artery to middle cerebral artery (STA-MCA) bypass for ischemia in the setting of carotid occlusion is being rigorously re-evaluated by the Carotid Occlusion Surgery Study (COSS) funded by the National Institutes of Health (NIH), which further stratifies patients as candidates for surgery if and only if they manifest with increased oxygen extraction fraction (OEF) on positron emission tomography (PET) scanning.² The Japanese EC-IC Bypass Trial (JET) is also rigorously evaluating bypass to treat cerebrovascular occlusive disease.³ Other potential patients for revascularization, using either surgical or endovascular techniques, include those with severe, symptomatic MCA stenosis.⁴⁻⁹ However, these patients should be considered very carefully because this group did worse after STA-MCA bypass in the EC-IC Bypass Study and because endovascular therapy carries a relatively high complication rate.^{1,4-9}

For those patients who do undergo bypass in the setting of ischemia, four areas of follow-up include: (1) long-term clinical follow-up for evidence of symptomatic ischemia; (2) neuropsychological testing; (3) bypass patency; and (4) changes in CBF. This article reviews potential follow-up for these patients. As outcome measures play a larger role in clinical follow-up and in reimbursement schedules, it is incumbent on the clinician to document as completely as possible the results of

revascularization. More important, rigorous follow-up assists patients with their own prognosis and progress.

NEUROLOGICAL FOLLOW-UP

In the past, an efficient neurological exam to include basic motor function and orientation would encompass the extent of review of a bypass patient. However, current literature suggests a more critical review of outcome measures to include functional and cognitive status (and the association between the two) is needed to adequately assess the clinical benefit of cerebral revascularization.

Functional status can be assessed by any number of stroke scales, with the most common being the NIH Stroke Scale (NIH-SS), the Modified Rankin Scale (MRS), the Barthel Index (BI), and the Stroke Specific Quality of Life Scale (SS-QOL). The NIH-SS allows one to quantify the clinical exam and is the industry standard in predicting poor outcomes after acute stroke.¹⁰ It can be administered at baseline, 2 hours post treatment, 24 hours post onset of symptoms, at 7 to 10 days, 3 months, and further out as needed. Both the MRS¹¹ and the BI¹² are commonly used scales that measure disability or dependence in activities of daily living in stroke patients. The MRS is widely used to assess global outcomes after stroke, while the BI records indicators of independence in terms of the disability caused by impairments. The SS-QOL Scale is a relatively new scale specific to stroke patients and is more comprehensive in attempting to capture higher levels of physical function and quality of life.¹³

While it is important to assess the functional status of bypass patients, it is becoming clear that this should be done in the context of assessing their

cognitive status, which is discussed in detail below. The association between cognitive status and functional outcomes in the setting of cerebral revascularization is unknown at this time and should be evaluated as secondary outcomes in future studies.

NEUROCOGNITIVE FOLLOW-UP

A body of literature exists evaluating neurocognitive improvement after cerebral revascularization. In 1977 Peerless and colleagues reported improvement in the quality of life and reduction in the signs of dementia in 50% of institutionalized patients who received bypass surgery for cerebrovascular disease, but they did not confirm with testing.¹⁴ Dull et al found significant neurobehavioral impairment in cerebral revascularization candidates, suggesting the importance of pre- and postop testing.¹⁵ In their study, the length of the longest preoperative symptom correlated with the degree of neuropsychological impairment.¹⁵ Binder and associates evaluated a small group of surgical and medically treated revascularization patients in 1982 with pre- and postoperative neurocognitive testing and found that both groups improved over time, postulating either spontaneous remission or a practice effect interpretation.¹⁶ Baird and colleagues found no clear correlation between the degree and pattern of intracranial stenosis to the extent of behavioral impairment in revascularization candidates, likely due to poor assessment of collateral blood flow.¹⁷ Brown and coworkers, however, found some correlation between cognitive function and reduction in regional CBF in bypass candidates.¹⁸ Payk et al demonstrated significant intellectual improvement in 5 psychological batteries in a series of 34 patients who underwent bypass for occlusive disease, though this study lacked a control group.¹⁹ Nielsen and associates assessed 33 symptomatic EC-IC bypass patients with cognitive testing preop and three months postop and compared these with results in 10 patients with normal cognition undergoing mi-

nor surgery.²⁰ The 10 right hemisphere patients had mild preop deficits and no significant postop deficits, whereas the left hemisphere patients had abnormal scores in 5 of 15 tests performed preoperatively but only 1 abnormal test finding (visual retention) 3 months postop.²⁰ This small study demonstrated intellectual improvement after bypass though patients in this study were not randomized for medical management. Baird and coworkers studied 95 cerebral revascularization candidates and found a modest correlation between neurocognitive deficits and real-world dysfunction.²¹

The EC-IC Bypass Study did not report improvement in cognitive function as a secondary outcome.¹ The COSS, in addition to determining whether stroke and death are reduced after bypass, will also assess clinical outcome using Rankin Scale Score, NIH-SS score, modified BI, and SS-QOL Assessment.² It will be interesting to see whether bypass patients demonstrate significant intellectual improvement over medically managed patients in this randomized, controlled study.

Specialized neurocognitive testing is important since this technique may demonstrate more significant deficits, or, more commonly, more extensive improvement than is captured by the functional status assessed by most stroke scales. Cardiac surgeons have more recently used formal neurocognitive testing to pick up subtle and marked temporary or permanent cognitive decline after cardiac bypass surgery.²²⁻²⁴ Neurocognitive deficits became quite apparent after aneurysm surgery in patients who were thought to have a normal neurological exam but in reality had some deficits when assessed with the Mini-Mental State Examination (MMSE) and MRS in the International Study for Unruptured Intracranial Aneurysms (ISUIA).²⁵ In contradistinction to aneurysm surgery, patients who undergo cerebral revascularization surgery tend to have improvements in their neurocognitive function, potentially another validation for the surgery. The COSS may elucidate some of the neurological improvements as a secondary endpoint.²

REPEATABLE BATTERY FOR THE ASSESSMENT OF NEUROPSYCHOLOGICAL STATUS

Neurocognitive testing for cerebral revascularization patients would ideally capture all pre- and postoperative deficits and would be easy to administer. Some of the tests noted above such as MRS, the SS-QOL, and the BI, though well tested and good for function, may miss some of the finer neurocognitive deficits. The MMSE is currently the most widely used screening instrument by health-care providers and offers excellent sensitivity for the rapid evaluation of cognitive status.²⁶ However, it cannot specify particular areas of cognitive impairment.²⁷ The Repeatable Battery for the Assessment of Neuropsychological Status (RBANS) was initially conceptualized as an instrument to be used in the detection and characterization of dementia in a geriatric population.²⁸ Similar to the Dementia Rating Scale (DRS) and the MMSE, the RBANS provides a brief yet sensitive method for assessing functioning across various cognitive domains.^{26,28,29}

The RBANS was developed to be used as a stand-alone "core battery" for detecting and differentiating dementia, and as a neuropsychological "screening battery" for use when lengthier batteries are inappropriate.³⁰ Specifically, the battery was designed with the following parameters: (1) brevity of administration; (2) difficulty level appropriate for the normal older adult through those with moderately severe dementia; (3) the ability to profile impairment across cognitive domains for the purpose of differential diagnosis and treatment planning; and (4) alternate forms to avoid practice effects, track disease progression, and note improvement in therapeutic interventions.²⁸ The RBANS therefore may lend itself to serial testing of cerebral bypass patients.

The RBANS battery takes less than 30 minutes to administer and yields scaled scores for the five cognitive domains of immediate memory, visuospatial/constructional, language, attention, and delayed memory.²⁸ The brevity of the

instrument makes it ideal for administration to older individuals and to individuals with compromised health, both groups that are prone to fatigue and less likely to endure the typical neuropsychological evaluation requiring 6 or more hours. Furthermore, unlike the RBANS, the standard neuropsychological battery lacks alternative forms which limit its clinical utility in tracking disease progression or recovery.

Research has examined the RBANS' ability to differentiate cortical dementias (i.e., Alzheimer's disease) from subcortical dementias (i.e., Huntington's disease, Parkinson's disease) and as a screening tool in patients with schizophrenia.^{31,32} Randolph et al compared the sensitivity of the RBANS to the Dementia Rating Scale.²⁸ The results indicated that the RBANS had greater sensitivity and specificity for identifying cognitive impairment in a demented population. The RBANS also demonstrated clear sensitivity to the type of impairment seen in individuals with schizophrenia.³³

The RBANS appears to provide the sensitivity and reliability required for repeated assessments. Additionally, it offers age-scaled norms and an alternative form to avoid practice effects. Although it may have some limitations, such as not providing a measure of problem solving/executive functioning, it appears to be a clinically useful screening instrument with adequate test-retest stability.³³ In summary, the RBANS may provide an additional neurocognitive test to evaluate perioperative cerebral bypass patients due to these attributes: rapidity of use, the ability to profile deficits across cognitive domains, age-scaled norms, and alternative forms to avoid the practice effect of serial exams.

RADIOGRAPHIC ASSESSMENT

Radiographic imaging plays an important role in assessing both the technical and functional success of EC-IC bypass for revascularization in the setting of cerebral ischemia. Although outcome measures relating to stroke reduction and neurocognitive and

neurological outcome are the ultimate endpoints in determining the efficacy of the intervention, imaging can provide concrete markers for the technical success of the procedure and for the anticipated benefits in terms of flow augmentation.

BYPASS PATENCY

The technical success of EC-IC bypass can be judged in the immediate, early, and delayed settings by assessing the patency of the bypass. Different modalities are useful based upon each of these time frames.

Intraoperative Assessment of Bypass Patency

Immediate appraisal of bypass patency following vessel anastomosis is desirable intraoperatively to identify inadequate or occluded grafts and to allow the opportunity to revise a technically unsuccessful anastomosis. Generally the immediate evaluation of patency is performed first by visual inspection or palpation of a pulse in the donor vessel; however, these techniques can be notoriously inaccurate and more objective measures are therefore routinely advisable.

In recent years, intraoperative digital subtraction angiography has become a commonly used and routine method for assessing cerebrovascular interventions during surgery.^{34–37} Angiographic images are considered the standard for visualizing anatomic patency. However, there are constraints inherent to performing angiography in the operating room environment, including the need for a specified intraoperative angiography team and equipment, and the increased technical difficulty of performing selective vessel catheterization imposed by operative patient positioning. Intraoperative angiography also prolongs surgery and adds exposure to an additional invasive procedure and ionizing radiation. Another emerging option for verification of immediate graft

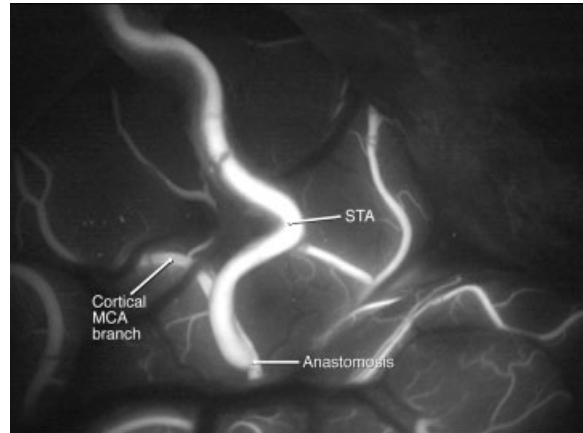


Figure 1 ICG angiography of bypass. ICG, indocyanine green.

patency, which avoids the disadvantages of standard angiography, is that of indocyanine green (ICG) angiography.^{38,39} This technique involves intravenous administration of ICG dye, which is then visualized by illuminating the operating field with infrared excitation light; the intravascular fluorescence of the dye can be visualized to demonstrate flow through the bypass (Fig. 1). This technique allows a simple method for documenting bypass patency.

Beyond anatomic visualization, techniques for assessing the flow dynamics of the bypass intraoperatively can provide additional valuable information. Microvascular Doppler is a simple real-time method for assessing the presence of flow in a bypass during surgery,⁴⁰ but its output is primarily qualitative and may not reliably distinguish between poor and robust flow. Quantitative assessment of patency can be reliably and repeatedly performed with direct measurements of flow using an ultrasonic perivascular flow probe device (Charbel Micro-flowprobe, Transonics Inc.).^{41–43} Such information regarding the flow rate through a bypass can be a particularly useful adjunct in assessing bypass function. For in situ vessel bypass such as STA-MCA or occipital artery-posterior inferior cerebellar artery bypass, which is most commonly used for revascularization in the setting of ischemia, quantitative flow measurements not only assess

intraoperative patency but can also predict the risk of future bypass failure.⁴¹ The ratio of flow in cc/min through the bypass (bypass flow) to the flow through the cut free end of the donor vessel prior to bypass (cut flow) provides an index termed the cut flow index (CFI). The CFI provides a sensitive predictor of postoperative bypass patency. In a study of 51 bypass procedures for flow augmentation in the setting of ischemia, a CFI below 0.5 (indicating bypass flow rates less than 50% of initial cut flow) was associated with a patency rate of 50%, compared with 92% in cases with CFI greater than 0.5.⁴¹ Reasons for a poor CFI included problems with the donor vessel (iatrogenic injury, atheromatous vessel), anastomosis (clot formation at suture line), or recipient vessel (inadequate recipient vessel or diffusely diseased vascular bed); identification of such problems can allow decision-making intraoperatively to rectify the problem and improve ultimate bypass success. Given that bypasses with a low CFI are often patent at the time of surgery, such results also highlight the notion that mere anatomic patency intraoperatively may not be as useful in predicting a successful bypass procedure as the assessment of intraoperative bypass flow.

Postoperative Assessment of Bypass Patency

Patency in the early postoperative period or for longer-term delayed follow-up has traditionally been performed with angiography.^{1,44-46} Grading systems to define the relative success of the bypass have been applied, attempting to classify the success of bypass function based upon the extent of the vascular tree filled by the graft.^{1,47} However, such anatomic grading systems have not been shown to correlate well with outcome.¹

For routine follow-up a less invasive modality than angiography is desirable. Clinical exam alone has been advocated as an adequate method for such follow-up. In a series of 415 STA-MCA bypasses for carotid occlusive disease, Sundt and colleagues reported 98% correlation between the findings on

physical examination (digital palpation of the donor vessel pedicle) and angiography in the first 260 cases who were studied with both.⁴⁸ The high angiographic patency (99%) makes the correlation less meaningful, because few occlusions were present to assess the specificity of the clinical exam. In cases where the branch of the STA not utilized for bypass is left open, a pulse in the STA pedicle could reflect flow through the patent native branch and erroneously suggest patency of the graft itself. In the remainder of their 415 patients, Sundt and associates advocated the use of physical examination and Doppler ultrasonography, abandoning routine angiography.

In the current era, new imaging modalities allow further options for noninvasive visualization of bypass patency. Both computed tomographic angiography (CTA) and magnetic resonance angiography (MRA) can be readily used to assess grafts postoperatively⁴⁹⁻⁵³ and for serial follow-up. CTA with 3-D reconstructions can provide exquisite details of the anatomy of the bypass (Fig. 2), serving as a convenient replacement for catheter angiography. Comparison of CTA and catheter angiography in small groups of patients following bypass have shown excellent correlation.^{52,53} Furthermore, whereas angiography may require multiple views to profile the anastomosis, which could mean prolonged catheterization and multiple contrast injections, once a CTA scan is performed, an infinite number of projections can be recreated from the images. Changes in the function of the bypass may potentially be inferred from changes in the caliber of the bypass, but more specific information regarding bypass function is difficult to obtain from the static images provided by both CTA and standard angiography. The rate of contrast dye filling and washout during angiographic procedures may give some indication of flow changes within a bypass, but is difficult to quantify and compare between studies. New MRA techniques, on the other hand, now provide the ability to quantify flow rates through cerebral vessels, adding a new dimension to the radiographic assessment of bypass grafts. The technique of quantitative MRA provides the ability

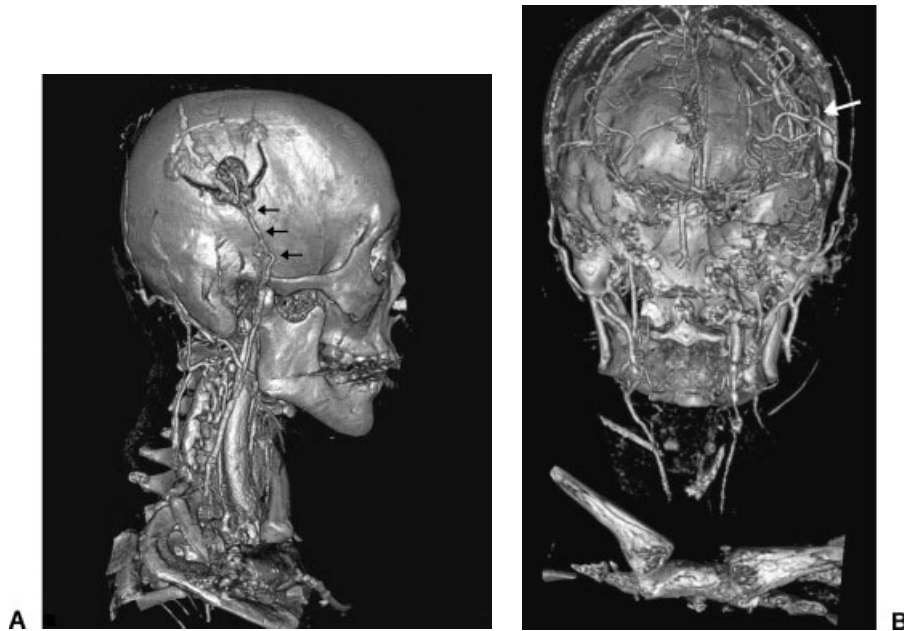


Figure 2 CTA demonstrating right STA-MCA bypass. (A) Lateral view with surface rendering demonstrating entry of the STA pedicle (arrows) through the craniotomy site. (B) PA view demonstrating the anastomosis (arrow). CTA, computed tomographic angiography; STA-MCA, superficial temporal artery-middle cerebral artery; PA, posterior-anterior. (Courtesy of P. Roc Chen, M.D.)

to measure flow in cc/min directly in vessels of interest⁵⁴⁻⁵⁸ (Fig. 3). Therefore, blood flow in a bypass can be measured and followed longitudinally not merely on the basis of its structural appearance, but on the basis of its flow,⁵⁹ providing a method for assessing long-term patency and function. There are

few studies addressing long-term efficacy of bypass function, but Schick et al have reported that bypass function can worsen over time, with failure occurring at an average of 2.7 years for STA-MCA grafts and 1.4 years for vein grafts in patients treated for ICA occlusion.⁶⁰ Serial follow-up is therefore an

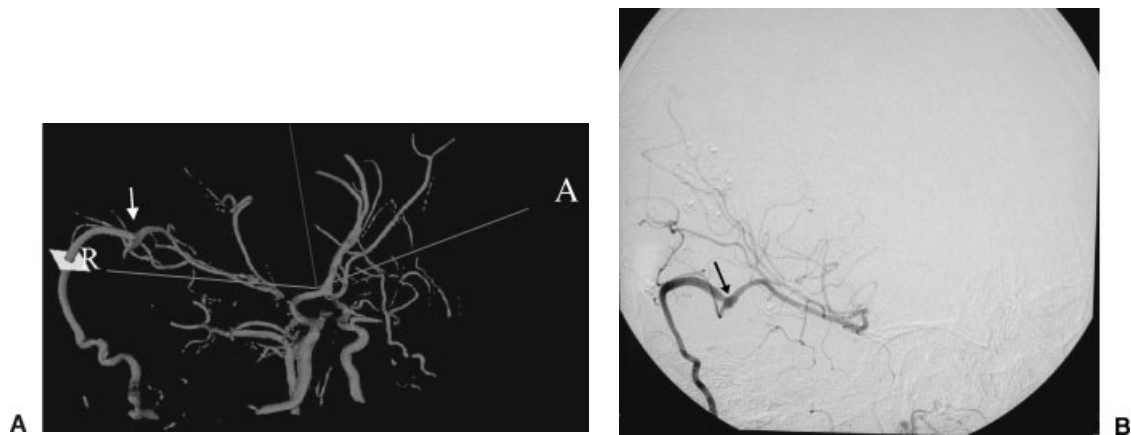


Figure 3 Right STA-MCA bypass for ischemic symptoms in the setting of right M1 vessel occlusion. (A) Angiogram and (B) 3-D MRA rendition used to define the bypass for quantitative flow measurement are shown. The arrow indicates the anastomosis. The flow in this robust STA bypass was 87 mL/min. STA-MCA, superficial temporal artery-middle cerebral artery; MRA, magnetic resonance angiography.

important aspect of judging the long-term success of the bypass.

CBF AND PERFUSION

There are a multitude of imaging modalities aimed at assessing adequacy of cerebral perfusion before and after cerebral revascularization surgery. These include PET, xenon CT, single positron emission computed tomography (SPECT), transcranial Doppler (TCD), CT, and MR modalities.⁶¹ Each modality has its own relative advantages and disadvantages. The goal of postoperative perfusion assessment is to identify improvements that can verify the success of the flow augmentation procedure.

The premise for current methods of assessing cerebral perfusion in the setting of cerebrovascular occlusive disease has been to identify those patients suffering from hemodynamic compromise as the source of ischemic symptoms. Degrees of cerebral hemodynamic impairment can be classified into two basic categories designated as Stage 1 and Stage 2 hemodynamic compromise. Stage 1 compromise refers to autoregulatory vasodilation, which occurs to maintain normal CBF by reducing the vascular resistance. As perfusion pressure decreases further, the capacity for maintaining normal blood flow by autoregulatory vasodilation is overcome, and CBF decreases; the brain compensates by increasing the extraction of oxygen from the blood to maintain normal cerebral oxygen metabolism referred to as Stage 2 compromise.

Stage 1 compromise can be inferred by quantifying perfusion parameters such as CBF and cerebral blood volume (CBV), with an increase in CBV or CBV/CBF ratio reflecting autoregulatory vasodilation. Such quantitative measurements can only be made reliably with PET, as is also the case with the assessment of increased OEF, which defines Stage 2 compromise (misery perfusion). Parameters indicating misery perfusion have been correlated with increased stroke incidence after

carotid occlusion.⁶² PET therefore has emerged as the gold standard predictive and quantitative tool for assessing critical hypoperfusion. Small studies have supported improvement in PET-measured misery perfusion following bypass,^{63,64} and this imaging modality is being used to select patients for the ongoing U.S. randomized clinical COSS trial to assess the efficacy of bypass in carotid occlusion.² However, PET is not a universally available imaging modality.

Identification of the presence and degree of autoregulatory vasodilation (Stage 1) can also be assessed with the use of paired blood flow measurements, with the initial measurement obtained at baseline and the second following a vasodilatory stimulus such as acetazolamide or hypercapnea or physiologic tasks such as hand movement. The response to the vasodilatory stimulus reflects cerebrovascular reserve capacity and can be graded as reduced, absent, or a paradoxical reduction compared with baseline, referred to as steal phenomenon. Paired measurements can be obtained using a variety of modalities: SPECT, xenon CT, TCD, PET, MR, and CT perfusion,⁶¹ and correlations with stroke risk have been described.⁶⁵⁻⁶⁹ Xenon CT is a quantitative perfusion assessment tool, with validation studies which have shown that it is a reliable method of assessing cerebral perfusion⁷⁰ but it is no longer widely available; other disadvantages include long acquisition time (and resultant difficulty with motion artifact) and occasional reactions of nausea or dizziness. SPECT imaging, which utilizes the radionuclide ^{99m}Tc-HMPAO, has been extensively used, but is primarily a qualitative tool subject to reader variability. It is also limited by availability and cost. A less costly method of assessment is the use of TCD with either Diamox or breath-holding challenge to assess for reserve.^{66,69} CT perfusion, using standard spiral CT scanner and an intravenous bolus injection of iodinated contrast, has the advantage of wide availability and holds the potential to provide quantitative data,^{71,72} although not currently established to do so. MR perfusion studies as well as the technique of functional imaging looking for

changes in the blood oxygen level dependent (BOLD) signal with physiologic tasks^{73,74} are promising modalities, but are also qualitative and not as yet well validated. The qualitative tools are useful to assess unilateral disease, but are generally inadequate in patients with bilateral or global pathology. There have been no studies to compare the relative accuracy of each of these modalities, although the challenge tests are all based on a similar premise of identifying loss of cerebrovascular reserve. The relative sensitivity and specificity of the tests may vary in this regard, and therefore it is important to use the same modality for comparing pre- and postoperative testing in a particular individual.

Several studies have also incorporated these paired blood flow measurements into the postoperative evaluation of patients following revascularization with bypass. Whereas some have reported improvement in hemodynamic parameters following bypass,^{47,75–79} others found improvement only in a subset of patients,^{80–82} or early improvement which was not long-lasting.^{83–85} Improvements may be most prominent in patients with the greatest degree of compromise preoperatively and are more often seen in cerebrovascular reserve rather than resting CBF.^{47,79,80} Nonetheless, changes in the postoperative setting are difficult to interpret definitively without comparison to similar non-operated patients, given that even spontaneous improvement in hemodynamic parameters have been described,^{86,87} presumably due to collateral formation.

Perfusion assessment even with the spectrum of modalities described has primarily shown its utility in the anterior circulation. Resolution for detecting critical posterior circulation hypoperfusion is limited.⁸⁸ An alternative tool to assess the adequacy of collateral circulation from a blood-flow standpoint entails quantitative MR flow measurement in the vertebrobasilar tree. The effect of occlusive vertebrobasilar disease upon distal territory can be surmised from flow in the basilar trunk and posterior cerebral arteries—if these flows are compromised based on flow measurements com-

pared with normative baselines, hemodynamic compromise can be inferred.⁸⁹ Follow-up of patients with reduced distal flow with such an algorithm has demonstrated higher stroke rates compared with the benign course in those without distal flow compromise.⁸⁹ Remeasurement of flows following intervention such as bypass could potentially assess the success of re-establishing adequate distal flow.

Ultimately, the success of the revascularization procedure is judged by its ability to favorably influence the natural history and stroke risk of the underlying cerebrovascular occlusive disease, an issue that is currently being addressed by the ongoing COSS² and JET³ studies in the U.S. and Japan. However, measures of blood flow and perfusion provide an adjunctive indication of bypass success. Establishing improvement in perfusion postoperatively is an important step in verifying that the bypass has adequately performed the goal of augmenting flow.

CONCLUSIONS

Cerebral revascularization in the setting of ischemia has had a resurgence of interest, spearheaded by the COSS and JET studies. The evolution of medicine has mandated that we are able to articulate outcomes from invasive procedures such as EC-IC bypass for ischemia. The various stroke scales such as the NIH-SS, MRS, the BI, and the SS-QOL scale provide an excellent assessment of functional status. More refined assessment of neurocognitive function may be achieved using the RBANS, among others.

Assessment of bypass patency intraoperatively can maximize the potential success of the procedure and may be accomplished with the qualitative microvascular Doppler probe or the quantitative Charbel Micro-flowprobe. An emerging option for verification of immediate graft patency is that of ICG angiography dye. Delayed patency can be followed with CTA or MRA, avoiding the morbidity and expense of catheter angiography.

The adequacy of cerebral perfusion can be assessed before and after cerebral revascularization surgery using one or more of a multitude of modalities that include PET, xenon CT, SPECT, TCD, CT, and MR. Identification of the presence and degree of autoregulatory vasodilation (Stage 1) can be assessed with the use of paired blood flow measurements, with the initial measurement obtained at baseline and the second following a vasodilatory stimulus. Paired measurements can also be obtained using a variety of modalities: SPECT, xenon CT, TCD, PET, MR, and CT perfusion. However, quantitative measurements can only be made reliably with PET, measuring increased OEF which defines Stage 2 compromise (misery perfusion). The goal of postoperative perfusion assessment is to identify improvements that can verify the success of the flow augmentation procedure.

DISCLAIMER

The views expressed in this article are those of the authors, and do not reflect the official policy or position of the Department of the Navy, Department of Defense, or the United States Government.

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