Contrast MR of the Brain after High-Perfusion Cardiopulmonary Bypass

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PURPOSE: To study the efficacy of contrast MR imaging in the evaluation of central nervous system complications in the cardiopulmonary bypass patient and attempt to explain their pathophysiology based on the MR appearance and the cardiopulmonary bypass protocol. **METHOD:** Nineteen patients were prospectively studied with contrast MR examinations the day before and 3 to 7 days after cardiopulmonary bypass, to determine the nature, extent, and number of new postoperative MR abnormalities. Cardiopulmonary bypass parameters used in our institution included: membrane oxygenation, arterial filtration with a pore size of 25 μm, and a relatively high perfusion rate to produce a cardiac index of 2.0 to 2.5 L/min per m^2. **RESULTS:** The preoperative noncontrast MR examination showed age-related changes and/or signs of ischemia in 60% of patients on the day before surgery. However, there was no abnormal enhancement or new T2 abnormalities on any postoperative MR examination to suggest hypoperfusion or emboli. None of the 19 patients developed overt neurologic deficits postoperatively. Review of the cardiopulmonary bypass protocol used indicated significant variations in technique at different institutions. **CONCLUSION:** Contrast MR imaging demonstrated no new abnormalities in patients after cardiopulmonary bypass performed with strict in-line arterial filtration and relatively high perfusion. MR imaging is feasible in the early postoperative period after cardiopulmonary bypass and may offer a convenient method for evaluation of the neurologic impact of technical factors associated with cardiopulmonary bypass.

Index terms: Surgery, complications; Brain, infarction; Heart; Brain, magnetic resonance; Iatrogenic disease or disorder

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Neurologic complications after cardiopulmonary bypass remain a significant problem. The frequency of stroke after cardiopulmonary bypass is generally cited at 2% (1). Although this is a relatively low percentage, considering 368,000 coronary artery bypass graft surgeries were performed in 1989 (2), this represents more than 7000 potential strokes per year attributable to coronary artery bypass graft surgery alone.

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The incidence of postoperative stroke can be even higher in certain high-risk patients. Increased age is associated with increased risk of neurologic complications (3). Brener et al (4) studied the effect of carotid artery disease in more than 4000 cardiac surgery patients. In patients without carotid artery disease, there was a 1.9% frequency of stroke or transient ischemic attack. With carotid artery stenosis, this increased to 9.2% and was even higher with an occluded carotid artery (15.6%).

Stroke represents only a small fraction of the neurologic sequelae of cardiopulmonary bypass. Confusion and disorientation are common after coronary artery bypass graft. Breuer et al (5) found 11.6% of patients were encephalopathic on postoperative day 4. Numerous neuropsychometric studies, performed before and after cardiac surgery, show immediate postoperative impairment in 55% to 83% (6). Six months later,

this decreases to 25%, and 1 year later most impairment has resolved with only 7% having a residual deficit.

The reason for these neurologic sequelae after cardiopulmonary bypass is unknown and difficult to ascertain. In addition, there is no convenient way to evaluate the neurologic consequences of new cardiopulmonary bypass techniques, because sensitive neuropsychometric testing is time consuming, and the relatively low frequency of overt stroke would require a large study population.

A recent study evaluating patients after cardiopulmonary bypass for valvular surgery with noncontrast magnetic resonance (MR) found new ischemic lesions demonstrated on T2-weighted images in 60% (DeLaPaz RL, Steinberg GK, Mitchell S, et al, MRI of Cerebral Injury Following Open Heart, Valve Replacement Surgery, presented at the 29th annual meeting of the ASNR, June 1991). This is similar to the percentage of patients with neuropsychometric impairment in other studies and suggests that MR may be a convenient method to assess neurologic sequelae after cardiopulmonary bypass. The same group has compared postoperative MR to analysis of cerebrospinal fluid enzymes including neuron-specific enolase and found MR more sensitive to subclinical ischemia (7).

Furthermore, contrast-enhanced MR has been reported to increase the detection sensitivity for early and subtle signs of ischemia (8, 9). MR contrast enhancement of ipsilateral ischemic areas in asymptomatic patients after carotid balloon test occlusion has been demonstrated (10). Our purpose was to investigate the efficacy of contrast-enhanced MR in the detection of central nervous system abnormalities after cardiopulmonary bypass and attempt to explain the possible pathophysiology of these complications based on the MR appearance and the cardiopulmonary bypass technique.

Patients and Methods

In this prospective study, MR examinations were performed on 19 consecutive coronary artery bypass graft patients before and after cardiopulmonary bypass. There were 10 men and nine women, 41 to 77 years of age. Excluded were patients who were claustrophobic, unstable intensive care unit patients, those who were above the scanner weight limit, and those who declined to participate in the study. All patients underwent cardiopulmonary bypass: 17 for coronary artery bypass graft, one for mitral valve replacement, and one for aortic valve replacement plus coronary artery bypass graft. Neurologic status was ascertained by chart review. Neuropsychometric testing was not performed, because this was intended to be a pilot study to evaluate the efficacy of contrast MR to detect neurologic changes in this patient population.

Cardiopulmonary Bypass Protocol

All cardiopulmonary bypass was done in the nonpulsatile mode with a Stöchert Shiley occlusive roller pump (Sorin Biomedical, Irvine, Calif), Medtronics (Anaheim, Calif) Maxima membrane oxygenator, and strict 25-μm inline arterial filtration. The system was primed with 2 L of Plasma-Lyte A, (Baxter, Deerfield, Ill), 18 g of mannitol, 25 mEq of sodium bicarbonate, 500 mL of hetastarch (or 50 g of albumin), and 10 000 U of heparin. A relatively high perfusion rate was set to maintain a flow of 2.0 to 2.5 L/min per m^2. The mean cross-clamp time was 100 minutes (range is 76 to 164 minutes). Mean blood pressure during cardiopulmonary bypass was 68 mmHg (range is 39 to 111 mmHg). Moderate systemic hypothermia (28 to 30°C) was employed in 16 patients, whereas the other three were maintained at a higher than 30°C core temperature.

MR Imaging

All examinations were performed on either a 0.5-T (Picker International, Highland Heights, Ohio) or 1.5-T (General Electric, Milwaukee, Wis) superconductive scanner. Only noncontrast MR studies were obtained, as a baseline, the day before surgery: coronal T1-weighted (350–583/20/2 [repetition time/echo time/excitations]) and axial T2-weighted (2000–2350/90–100/1–2) spin-echo pulse sequences. Three to 7 days after surgery, a follow-up MR examination included both noncontrast and contrast studies. The noncontrast MR included at least one T1-weighted and one T2-weighted image to match the preoperative images and was done on the same machine for ease in comparison. Postcontrast T1-weighted images were obtained immediately after intravenous injection of 0.1 mmol/kg of gadopentetate dimeglumine using identical precontrast image parameters.

All MR examinations were evaluated for signs of old or recent ischemia by two radiologists who were blinded to the patients' history and clinical status. Special attention was focused on the corticomedullary junction, in which emboli tend to lodge, and the watershed zones, in which insufficient perfusion would be demonstrated.

Results

Eleven patients had abnormal preoperative MR examinations; some had more than one type of lesion, including nine with periventricular white

matter lesions, four with lacunar infarcts in the basal ganglion, and one with an old right occipital infarction. None of these lesions was associated with positive mass effect to suggest recent ischemia. In comparison, there was no abnormal enhancement or new T2 changes, especially in the corticomedullary junction or watershed region, on any of the postoperative MR examinations to suggest hypoperfusion or emboli. None of the 19 patients developed overt neurologic deficits after surgery.

Discussion

Many studies have been undertaken to determine the frequency and cause of cerebral dysfunction after cardiac surgery. Unfortunately, there are numerous variables to consider, making this a difficult problem to resolve. In simple terms, strokes are likely caused by emboli and/or hypoperfusion. MR imaging theoretically should be able to distinguish between emboli and hypoperfusion as causes of cerebral dysfunction or even occult ischemia. We would expect embolic injury to be multifocal and predisposed to the corticomedullary junction. Hypoperfusion, on the other hand, should be localized in the arterial watershed zones. A previous noncontrast MR study evaluating cardiac surgery patients found new T2 signal abnormalities in both areas (DeLaPaz RL, Steinberg GK, Mitchell S, et al, MRI of Cerebral Injury following Open Heart, Valve Replacement Surgery, presented at the 29th annual meeting of the ASNR, June, 1991). Whether cerebral dysfunction or encephalopathy is also caused by emboli or hypoperfusion is unknown.

The possible sources of emboli are legion; they include air, oil, fat, aggregated platelets, fibrin, thrombi, or debris from atheromatous plaque. Hise et al (11) concluded that emboli were a frequent cause of postoperative strokes because 13 of 30 documented neurologic events after coronary artery bypass graft had an appearance consistent with multiple cerebral emboli on computed tomography. The method of oxygenation and filtration for these patients, however, was not reported. Moody et al (12) have presented histologic evidence of microemboli in both dogs and humans who have undergone cardiopulmonary bypass in the form of small focal dilatations in terminal arterioles and capillaries. They speculate that gas or fat is a possible source because the dilatations are empty after histologic processing. In theory, membrane oxygenation and strict in-line arterial filtration as used in our institution should greatly reduce or eliminate the incidence of emboli larger than 25 μm. However, smaller emboli could penetrate the filter. Also, some believe filtration can promote platelet aggregation and/or mechanical red blood cell breakdown leading to lipid membrane emboli.

Blauth et al (13) support membrane oxygenation as a method to decrease microemboli during cardiopulmonary bypass by documenting retinal microemboli and perfusion defects by fluorescein angiography in 100% of patients undergoing cardiopulmonary bypass with bubble oxygenation. Over half of the patients in the membrane oxygenation group had normal post-cardiopulmonary bypass retinas. However, this study also points out how extremely small these emboli are. Such small microemboli could possibly be missed by MR imaging.

There is no consensus in the literature on the importance of hypoperfusion as a cause of postoperative cerebral dysfunction. It is well known that the minimum cerebral blood flow requirement for viability is lower under general anesthesia and hypothermia than the normal requirement of 35–55 mL/100 g per minute (14, 15). Under normal circumstances, symptoms do not develop until cerebral blood flow drops below 20 mL/100 g per minute (15). However, the absolute minimum requirement during cardiopulmonary bypass has not been established. Brusino et al (16) measured cerebral blood flow with xenon-133 clearance during cardiopulmonary bypass with a cardiac index of 1.6. The range of cerebral blood flow in their 20 patients was 13.8 to 37.5 mL/100 g per minute, and none developed a stroke. It is likely that minimum flow requirements to prevent cerebral ischemia vary from patient to patient based on multiple factors such as carotid disease and the amount of dependence on collateral circulation. This is supported by the fact that the frequency of strokes after cardiac surgery in patients with an occluded carotid is eight times higher than in patients without carotid disease (4). Higher flows during cardiopulmonary bypass therefore may reduce the risk of hypoperfusion or watershed type ischemia. This is controversial, however, as higher flow rates could potentially carry more emboli to the brain.

Our results differ significantly from the high percentage of postoperative MR abnormalities in the noncontrast study of valve replacement patients by DeLaPaz et al (DeLaPaz RL, Steinberg

GK, Mitchell S, et al, MRI of Cerebral Injury following Open Heart, Valve Replacement Surgery, presented at the 29th annual meeting of the ASNR, June 1991). The exact reason for the absence of MR changes after cardiopulmonary bypass in our patient population remains to be identified, but it may be related to patient selection, time delay between surgery and imaging, and/or technical factors such as filtration pore size and perfusion rate. Selection of relatively stable patients for elective surgery may exclude the highest risk patients. Also, the valvular surgery in the previous study, as compared with coronary artery bypass graft, is associated with a higher risk of neurologic complications. The patients we evaluated were stable enough to undertake a precontrast MR study, and most underwent coronary artery bypass graft.

The 3- to 7-day postoperative delay before MR imaging may have been a factor contributing to the lack of abnormal enhancement found in our patients. Simonson et al (10) reported that transient and asymptomatic ischemia can be detected as abnormal parenchymal enhancement on contrast MR imaging. Generally, abnormal enhancement is seen within several hours after the ischemic event and begins to subside by 2 to 3 days. T2 signal changes develop later than abnormal enhancement, often days later. Therefore, reversible signs of ischemia, especially arterial and parenchymal enhancement, may have already resolved in the 3- to 7-day delay before MR scanning. Despite this, no new T2 abnormalities were observed. This correlates well with a previous study by Vik et al (17) in which nine coronary artery bypass graft patients showed no new MR lesions after surgery. The cardiopulmonary bypass in these patients included membrane oxygenation and flow rates of 1.0 to 1.5 L/min per m^2. Filtration was not mentioned. A similar European study found new deep white matter lesions in six of 20 patients (30%) after cardiopulmonary bypass, all but one of whom underwent bubble oxygenation without a filter. The remaining patients had membrane oxygenation (Hamid SK, Toner I, Peden C, Assessment of Cerebral Outcome following Coronary Artery Bypass [CABG] Using Magnetic Resonance Imaging and Neuropsychometric Testing [NP], Presented at the 11th annual meeting of the Society for Magnetic Resonance in Medicine, 1992). Four of the six had associated neuropsychometric deterioration.

In addition to patient selection, type of surgical procedure (coronary artery bypass graft), and timing of imaging, technical factors associated with cardiopulmonary bypass may partially explain the distinctly different results seen in the study by Vik et al and the current study as compared with those of others. With a zero incidence of new MR abnormalities in our patients, presumably the cardiopulmonary bypass technique used must be at least adequate to prevent significant emboli and watershed infarctions. With strict in-line arterial filtration to eliminate emboli larger than 25 μm, we found no new lesion localized in the corticomedullary junction. Similarly, with the relative high perfusion during cardiopulmonary bypass no watershed ischemia was evident on our postoperative MR images.

In conclusion, the cause of cerebral dysfunction after cardiopulmonary bypass is most likely multifactorial. This study suggests that cerebral lesions are not an obligate sequela of cardiopulmonary bypass and may be prevented by appropriate cardiopulmonary bypass technique. Studies evaluating cardiopulmonary bypass must state the bypass parameters, because a large variety of techniques are now in use. MR imaging may provide a convenient method to assess specific factors and techniques associated with cardiopulmonary bypass and to evaluate proposed improvements, in terms of potential for cerebral ischemia.

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