Direct Spinal Cord Perfusion Pressure Monitoring in Extensive Distal Aortic Aneurysm Repair

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Background. **Although maintenance of adequate spinal cord perfusion pressure (SCPP) by the paraspinal collateral network is critical to the success of surgical and endovascular repair of descending thoracic and thoracoabdominal aortic aneurysms, direct monitoring of SCPP has not previously been described.**

Methods. **A catheter was inserted into the distal end of a ligated thoracic segmental artery (SA) (T6 to L1) in 13 patients, 7 of whom underwent descending thoracic and thoracoabdominal aortic aneurysm repair using deep hypothermic circulatory arrest. Spinal cord perfusion pressure was recorded from this catheter before, during, and after serial SA sacrifice, in pairs, from T3 through L4, at 32°C. Somatosensory and motor evoked potentials were also monitored during SA sacrifice and until 1 hour after cardiopulmonary bypass. Target mean arterial pressure was 90 mm Hg during SA sacrifice and after nonpulsatile cardiopulmonary bypass, and 60 mm Hg during cardiopulmonary bypass.**

Results. **A mean of 9.8 ± 2.6 SAs were sacrificed without somatosensory and motor evoked potential loss. Spinal cord perfusion pressure fell from 62 ± 12 mm Hg (76% ± 11% of mean arterial pressure) before SA sacrifice to 53 ± 13 mm Hg (58% ± 15% of mean arterial pressure) after SA clamping. The most significant drop occurred with initiation of nonpulsatile cardiopulmonary bypass, reaching 29 ± 11 mm Hg (46% ± 18% of mean arterial pressure) before deep hypothermic circulatory arrest. Spinal cord perfusion pressure recovered during rewarming to 40 ± 14 mm Hg (51% ± 20% of mean arterial pressure), and further within the first hour of reestablished pulsatile flow. Somatosensory and motor evoked potentials returned in all patients intraoperatively. Recovery of SCPP began intraoperatively, and in 5 patients with prolonged monitoring, continued during the first 24 hours postoperatively. All but 1 patient, who had remarkably low postoperative SCPPs and experienced paraparesis, regained normal spinal cord function.**

Conclusions. **This study supports experimental data showing that SCPP drops markedly but then recovers gradually during the first several hours after extensive SA sacrifice. Direct monitoring may help prevent a fall of SCPP below levels critical for spinal cord recovery after surgery and endovascular repair of descending thoracic and thoracoabdominal aortic aneurysms.**

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Paraplegia remains the most devastating complication after repair of extensive descending thoracic (DTA) and thoracoabdominal aortic aneurysms (TAAA). The maintenance of adequate spinal cord perfusion pressure (SCPP) is critical to the success of open and endovascular repair of DTAs and TAAAs to prevent spinal cord ischemia when blood flow to the segmental arteries (SAs) is interrupted.

Monitoring of spinal cord function using motor (MEP) or somatosensory evoked potentials (SSEP) is widely accepted in the assessment of intraoperative spinal cord viability during aortic procedures, but is an indirect measurement of the adequacy of spinal cord perfusion [1–6]. If MEPs or SSEPs diminish, the response usually involves anesthetic and hemodynamic maneuvers to improve spinal cord perfusion—chiefly by increasing mean arterial pressure (MAP) and improving cerebrospinal fluid (CSF) drainage—but the assessment of the efficacy of these measures is likewise indirect. It is possible that inadequate spinal cord perfusion may occur even when MEP and SSEP monitoring shows no cause for alarm, and that a more direct, sensitive way of monitoring spinal cord perfusion could be helpful intraoperatively, although the presence of intact MEP and SSEP already provides considerable reassurance of adequate intraoperative spinal cord perfusion.

A recent retrospective study of our clinical cases has suggested, however, that spinal cord vulnerability to inadequate perfusion is likely to be highest not during operation, but in the early postoperative period, and that inadequate perfusion resulting in spinal cord injury may occur with systemic pressures below the individual patient's usual blood pressure even though those systemic pressures fall within limits usually regarded as normal

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Abbreviations and Acronyms

CPB	= cardiopulmonary bypass
CSF	= cerebrospinal fluid
CVP	= central venous pressure
DTA	= descending thoracic aneurysm
MAP	= mean arterial pressure
MEP	= motor evoked potential
SA	= segmental artery
SCPP	= spinal cord perfusion pressure
SSEP	= somatosensory evoked potential
TAAA	= thoracoabdominal aortic aneurysm

[7]. The major contribution of direct monitoring of SCPP is therefore likely to be in preventing delayed-onset paraplegia. We think that SCPP monitoring during the first 24 hours postoperatively—at a time when monitoring MEPs is not possible, and SSEP monitoring is at best difficult—is likely to prove invaluable.

To measure the adequacy of spinal cord perfusion more directly intraoperatively and to enable surveillance into the early postoperative interval, we adapted for clinical use a method of direct measurement of SA pressure that had previously been developed in experimental studies of spinal cord blood flow after SA ligation [8]. The correlation in our experimental studies between the measurement of SCPP and microsphere determinations of spinal cord blood flow as well as functional and histologic outcomes convinced us that this technique would be a valuable guide to hemodynamic management for patients undergoing repair of DTA and TAAA in which spinal cord injury is a concern. What follows is our initial clinical experience with this new monitoring tool.

Patients and Methods

Patients

From January 2006 to May 2008, 13 patients underwent DTA and TAAA repair with routine SSEP and MEP monitoring and additional SA catheter placement for SCPP monitoring. Specific consent for this procedure was not obtained because the SCPP pressure measurement was part of a continuous program of improving monitoring of spinal cord protection during aortic surgery, and believed to be of direct benefit to the patients being monitored. The Institutional Review Board approval for presentation of these retrospective results was waived because individual patients were not identified. Table 1 lists demographics and clinical patient profiles.

Operative Management

The aorta was accessed through a left thoracotomy or thoracoabdominal incision. The diaphragm was divided circumferentially. The infradiaphragmatic aorta was exposed through a retroperitoneal approach. The aneurysm was gradually dissected free from mediastinal (and retroperitoneal) tissue. The intercostal and lumbar arteries were dissected and temporarily occluded. If MEPs and SSEPs remained unchanged, the SAs were sacrificed before opening the aneurysm to avoid backbleeding and possible steal from the spinal cord circulation. The process of neurophysiologic evaluation and sacrifice of each pair of SAs took 3 to 5 minutes. If no changes in MEP were noted during the next 10 minutes or so, the next section of the aorta was dissected, 1 to 3 more SAs were occluded, and evoked potentials were once again assessed. This process was repeated until the entire aneurysm had been mobilized. In general—in view of its importance in supporting spinal cord perfusion—clamping of the left subclavian artery was avoided, and the internal mammary artery and the superior epigastric axis were preserved. If clamping of the distal aorta was not feasible or was unsafe, the distal anastomosis was performed first, and distal perfusion restored after cross-clamping of the graft. For the visceral segment, a beveled anastomosis was frequently used. If the visceral segment required circumferential replacement, the visceral vessels were occluded with a balloon catheter and intermittently perfused with cold blood before they were connected using intervening graft segments (8 to 12 mm Dacron). Vascular Dacron grafts (Hemashield; Boston Scientific, Natick, MA; 18 to 28 mm) with as many as three additional side arms were implanted in an end-to-end fashion.

Bypass Technique

All operations were carried out under moderate hypothermia (32°C), and distal aortic perfusion or, if needed, deep hypothermia was used with circulatory arrest initiated at a bladder temperature of 14°C and jugular bulb cerebral venous saturation of at least 95%.

HYPOTHERMIC CIRCULATORY ARREST. Hypothermic circulatory arrest was effected by surface and perfusion cooling. Adequate cerebral hypothermia was ensured by cooling to an esophageal temperature of 12° to 15°C, and maintaining a jugular venous saturation greater than 95%. The head was packed circumferentially in ice.

The proximal anastomosis was carried out during hypothermic circulatory arrest. A brief period of perfusion by means of the right atrial catheter was used to clear air from the proximal aorta and allow suctioning to remove any putative particulate debris from the area of the anastomosis. Proximal body and coronary perfusion (selective cerebral perfusion) was then restored by perfusion through the axillary artery or a side branch in the aortic graft.

Perfusion warming was performed at the end of the procedure with the gradient between the esophageal and blood temperature maintained at less than 10°C. Warming was maintained until the esophageal temperature reached 35°C and bladder temperature was in excess of 32°C.

DISTAL AORTIC PERFUSION. Distal aortic perfusion was established through femorofemoral cannulation (also using the inferior vena cava, the right atrium, or, in one case, the inferior pulmonary vein for drainage) and an in-line oxygenator (BioMedicus Circuit, Medtronic Biomedicus