Thoracic and thoracoabdominal aortic aneurysm repair: Use of evoked potential monitoring in 118 patients

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Purpose: Paraplegia is the most dreaded and severe complication of surgery on the descending thoracic aorta (TAA) and thoracoabdominal aorta (TAAA). The functional integrity of the spinal cord can be monitored by means of intraoperative recording of myogenic-evoked responses after transcranial electrical stimulation (tcMEP) and somatosensory-evoked potential (SEP) monitoring. In this study, we evaluated the results of evoked potential monitoring and the adequacy of the strategy followed.

Method: The spinal cord of 118 patients (78 men; age, 65 ± 12 years; 79 TAAAs, 39 TAAs) undergoing surgery on the TAA or TAAA was monitored with tcMEP and SEP. Spinal cord protection was achieved by means of a multimodality approach: moderate hypothermia (32°C rectal temperature), continuous cerebrospinal fluid drainage to keep the pressure less than 10 mm Hg, reimplantation of intercostal arteries, left ventricular bypass grafting, and staged clamping. In the case of evoked potential changes more than 50% of baseline, the strategy was adjusted: reattachment of more segmental arteries when technically feasible, higher distal and proximal perfusion pressures, and enhanced cerebrospinal fluid drainage.

Results: Forty-two of 118 patients (35.6%) had a more than 50% of baseline tcMEP reduction during cross-clamping. At this point, only 5 of those 42 cases were also associated with SEP reduction of more than 50% of baseline. On the basis of the tcMEP findings, the strategy was adjusted. Five patients had postoperative paraplegia (4.2%).

Conclusion: tcMEP monitoring seems to be a useful adjunct of the protective techniques and may cause substantial adjustments in strategy, reducing the incidence of postoperative paraplegia. (J Vasc Surg 2001;34:1035-40.)
cute block. Before a neuromuscular blocking drug was given, the compound muscle action potential (CMAP) was obtained from thethenar eminence after supramaximal stimulation of the median nerve at the wrist with a general evoked response stimulator (SMP 3100, Nihon Kohden) triggered from a personal computer (PC). An atracurium or mivacurium infusion was used as a means of maintaining the first twitch T1 of the train of four at 45% to 55% of the control CMAP. The T1 response was displayed on the computer screen. The patient was positioned on a beanbag (Olympic Medical, Seattle, Wash) in the right lateral decubitus position, and two intrathecal catheters (one for monitoring intrathecal pressure, one for drainage of cerebrospinal fluid) were placed via the second and third lumbar interspaces. Routine anesthetic monitoring for major vascular surgery was performed and electronically recorded every 30 seconds (Datex, Helsinki, Finland).

**Table I. Patient characteristics**

<table>
<thead>
<tr>
<th></th>
<th>TAAA (n = 79)</th>
<th>TAA (n = 39)</th>
<th>All (n = 118)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>65 ± 10</td>
<td>67 ± 12</td>
<td>65 ± 12</td>
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<tr>
<td>Sex (%)</td>
<td>29 F (36.7)/50 M</td>
<td>11 F (28.2)/28 M</td>
<td>40 F (33.9)/78 M</td>
</tr>
<tr>
<td>Total cross-clamp time (minutes)</td>
<td>152 ± 45</td>
<td>93 ± 40</td>
<td>130 ± 53</td>
</tr>
<tr>
<td>Number of reattached intercostals</td>
<td>418</td>
<td>110</td>
<td>528</td>
</tr>
<tr>
<td>Paraplegic (%)</td>
<td>5 (6.3)</td>
<td>0 (0)</td>
<td>5 (4.2)</td>
</tr>
<tr>
<td>Mortality (%)</td>
<td>3 (3.8)</td>
<td>1 (2.6)</td>
<td>4 (3.4)</td>
</tr>
<tr>
<td>During cross-clamping of critical aortic segment</td>
<td>tcMEP ≤ 50% of baseline (patients with paraplegia)</td>
<td>33 (4)</td>
<td>9 (0)</td>
</tr>
<tr>
<td></td>
<td>tcMEP and SEP ≤ 50% (patients with paraplegia)</td>
<td>5 (1)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>After 5 minutes of reperfusion of critical aortic segment</td>
<td>tcMEP ≤ 50% of baseline (patients with paraplegia)</td>
<td>20 (4)</td>
<td>5 (0)</td>
</tr>
<tr>
<td></td>
<td>tcMEP and SEP ≤ 50% (patients with paraplegia)</td>
<td>3 (0)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>During closure of the skin</td>
<td>tcMEP ≤ 50% of baseline (patients with paraplegia)</td>
<td>13 (4)</td>
<td>5 (0)</td>
</tr>
<tr>
<td></td>
<td>tcMEP and SEP ≤ 50% (patients with paraplegia)</td>
<td>4 (1)</td>
<td>0 (0)</td>
</tr>
</tbody>
</table>

F, Female; M, male; tcMEP, myogenic evoked responses after transcranial electrical stimulation; SEP, somatosensory-evoked potential.
Surgical technique. A posterolateral thoracotomy in the fifth or sixth intercostal space was performed, extending in a median laparotomy after arcus costae transsection. Simultaneously, the left common femoral artery was dissected free. After opening the pericardium, the left atrium and left femoral artery were cannulated, connected to the Biomedicus pump, and bypass grafting commenced. The mean proximal arterial pressure was maintained between 60 and 100 mm Hg, and the mean distal arterial line pressure was maintained higher than 60 mm Hg by adjusting bypass grafting flows and intravascular volume and with nitroprusside infusion. Spontaneous hypothermia on bypass grafting was tolerated (32-34°C, as measured by means of a rectal probe). When aneurysm configuration allowed us to do so, we used staged clamping to maximize the beneficial effect of the distal perfusion with the left ventricular bypass grafting procedure. After incision of the aneurysm, large intercostal arteries localized within the aneurysm were temporarily occluded with a balloon catheter. A woven Dacron vascular prosthesis (Intervascular, La Ciotat, France) was used. In all patients, the proximal anastomosis was created first. After testing this anastomosis, large intercostal arteries, especially between T-8 and L-2, were reimplanted into the prosthesis and reperfused. Rewarming to a rectal temperature of 36 to 37°C was done while the distal anastomosis was being performed and after reperfusion of all reimplanted intercostal and lumbar vessels. After terminating the left ventricular bypass grafting procedure, the blood was retransfused into the left atrium whenever possible. The cleaned aneurysm wall was closed over the graft for additional protection.

Multimodality strategy. Spinal cord protection was achieved by means of a multimodality approach: moderate hypothermia (32°C rectal temperature), left ventricular bypass grafting, staged clamping, reimplantation of intercostal arteries, and cerebrospinal fluid drainage were continued throughout the procedure as a means of maintaining the intrathecal pressure below 10 mm Hg. In addition, when tc MEP decreased more than 50% of baseline after a few minutes of excluding a particular aneurysmal segment, the intercostal arteries within this segment were considered to be critical to the spinal circulation and were promptly reattached to that particular aortic segment. At the same time, higher perfusion pressures and more cerebrospinal fluid drainage were accomplished. Retrospectively, we analyzed the SEP at the point when the tc MEP was below 50% of baseline. On empirical grounds, we have chosen a decrease of more than 50% of baseline in tc MEP as the borderline. We assume that an amplitude decrease more than two times the coefficient of variation (20%-25%) provides optimal detection of beginning spinal cord malfunction.

Statistical analysis. Associations between tc MEP and postoperative paraplegia were analyzed by means of logistic regression in SPSS software (Statistical Package for the Social Sciences, Chicago, Ill.). The independent sample t test in SPSS was used as a means of comparing the mean differences of age, total clamp time (minutes), and number of reattached intercostals between the patients with tc MEP of 50% or less of baseline and patients with tc MEP more than 50% of baseline. A P value less than .05 was considered to be significant.

RESULTS

A total of 118 patients were included in this study. Twelve patients with incomplete intraoperative tc MEP and SEP data were excluded; the paraplegic rate of these patients was 0%. During aortic cross-clamping, the mean core body temperature was 32.0 ± 0.4°C. The in-hospital mortality rate was 3.4% (Table I). The causes of death were cardiac failure in one patient (this patient showed paraplegia also), postoperative retrograde aortic dissection into the ascending aorta in another patient, and two patients had bronchopneumonia resulting in fulminating septicemia with multiple organ failure.

Forty-two patients had a tc MEP decrease of more than 50% of baseline during cross-clamping (Table I).
only five patients, this tcMEP decrease was accompanied by a SEP decrease of more than 50% of baseline. The total strategy was adjusted in 42 patients (35.6% of all patients) during cross-clamping on the basis of a more than 50% decrease of the baseline tcMEP. Five of those patients (11.9%), however, had paraplegia afterwards.

Most vessels were reimplanted between the level of T8 and L1: 12.8% at T8, 15.3% at T9, 15.7% at T10, 10.4% at T11, 5.9% at T12, and 3.2% at L1.

The number of patients with a tcMEP of 50% of baseline or less decreased from 42 during cross-clamping to 25 patients after 5 minutes of reperfusion, and further decreased to 18 patients during closure of the skin. Table II shows the tcMEP and SEP recordings in the percent of baseline of the five patients with paraplegia (4.2%; 3 patients with postoperative paraplegia in 1995, 1 patient with postoperative paraplegia in 1996, and 1 patient with postoperative paraplegia in 1997) during operation for TAAA. No patient was paraplegic after surgery for TAA. In only one patient with postoperative paraplegia, a tcMEP decrease of more than 50% of baseline was accompanied by a SEP decrease of more than 50% of baseline during cross-clamping.

During cross-clamping, significantly more intercostals were reimplanted, and there was a significantly longer cross-clamp time in the group of patients with tcMEP of 50% or less of baseline. These significant differences were not detected after 5 minutes of reperfusion between the group of patients with tcMEP and SEP more than 50% of baseline and the patients with tcMEP and SEP of 50% of baseline or less. During closure of the skin, however, significantly more intercostals were reimplanted in the group of patients with tcMEP of 50% of baseline or less at that moment (Table III).

Table IV shows the tcMEP associated with postoperative paraplegia. The relative risk of paraplegia in the group of patients with tcMEP of 50% of baseline or less 5 minutes after reperfusion is 21 times higher than the group of patients with tcMEP more than 50% of baseline. During closure of the skin, the relative risk was 30.9 ($P = .002$) for tcMEP of 50% of baseline or less, compared with tcMEP more than 50% of baseline at that moment.

**DISCUSSION**

Spinal cord injury is a result of the aortic cross-clamping causing hypoperfusion of the spinal cord. The exclusion of critical arteries for spinal blood supply during replacement of the descending aortic segment and reperfusion injury can be responsible for the occurrence of paraplegia. Paraplegia may also occur as a consequence of thrombosis and embolization of these intercostal arteries. The complexity of spinal cord ischemia may hamper the goal of evoked potential monitoring, which is to detect changes in spinal cord function early enough to take precautions to prevent postoperative paraplegia. Distal perfusion with left ventricular bypass grafting and monitoring evoked potentials, especially tcMEPs, as a means of identifying critical vessels or suboptimal perfusion pressures, can avoid the risk of paraplegia. Our results (Table I) show that in 42 of 118 patients, we tried to prevent spinal cord injury by increasing distal and proximal aortic pressure and with cerebrospinal fluid drainage and reattachment of intercostal arteries. Five cases of paraplegia, however, occurred in this group of patients. The question arises...
whether the prevalence of spinal cord injury would have been increased from 4.2% to 35% if we had not paid attention to the results of spinal cord monitoring. If appropriate measures during the procedure would not be effectuated, an answer would readily be provided. For ethical reasons, this was not accomplished. tcMEPs were recorded during the operation only, and spinal cord ischemia could lead to edema in the gray matter with subsequently manifest late-onset spinal cord injury after a certain period of time.

The tcMEP reduction of more than 50% of baseline during closure of the skin (Tables I, II, and III) may reflect ongoing malfunction of the corticospinal pathway. Comparing both groups (ie, tcMEP ≤50% of baseline and tcMEP > 50% of baseline), the relative risk was 3.4 during cross-clamping. Without the protective interventions that were taken, however, the relative risk increases to 31 during closure of the skin. This may be caused by difficulty in reestablishment of spinal cord blood flow, beginning reperfusion injury at that very moment, or both. The observation made on the next day that tcMEP was not recordable in those cases with paraplegia makes this assumption very likely. Of course, not all the cases with tcMEP less than 50% of baseline during closure of skin showed paraplegia afterwards, suggesting reversible phenomena in most of the cases. To have a better understanding of the pathophysiology of spinal cord ischemia, we suggest extending the tcMEP monitoring during the direct postoperative period. Additionally, the determination of S-100 protein in cerebrospinal fluid could be a marker of ischemia in defining the range in which tcMEP changes are pathognomonic for impending irreversible spinal cord ischemia. If so, this would help both to create more insight in the significance of the percent level of baseline we use and the biochemical pathways leading in time to spinal cord injury.

The tcMEP data seem to have a better correlation with the neurologic outcome than SEP data. SEP data reflect the conductive capabilities of the white matter in the dorsal horn, which is less sensitive to hypoxia than the alpha motoneuron in the grey matter of the spinal cord. The dorsal horn has a lower metabolic rate than the anterior horn. This vulnerability of the anterior horn has been demonstrated in a clinical sense and with MRI studies.

To reduce the false-positive results of intraoperative tcMEP recording, the influence of the anesthetic and neuromuscular blocking agents on the tcMEP recording should be kept low. The recording of muscle responses to six-pulse transcranial electrical stimulation during low-dose propofol/fentanyl/50% nitrous oxide anesthesia and a neuromuscular block aimed at a T1 of 45% to 55% seem to be a good combination of sensitivity and clinical usefulness. Reattachment of intercostals during cross-clamping seems to have a positive effect on the spinal cord circulation, leading to a decreased incidence of borderline spinal cord perfusion during closure of the skin. Safi et al showed the importance of reattachment of intercostal arteries and reported the relationship between lower thoracic artery ligation and neurologic deficit. The thoracoabdominal spinal cord blood supply is unlikely to depend on one segmental artery. In this study, significantly more intercostals were reimplanted in those patients with tcMEP of 50% of baseline or less during cross-clamping and during closure of the skin. Next to the reimplanted intercostals, the other components of the strategy such as cerebrospinal fluid drainage and optimal perfusion pressures are important protective measures in the perioperative and postoperative periods. The data from this study show that tcMEP seems to be an effective guide in our protective multimodality strategy.

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REFERENCES

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THE PACIFIC VASCULAR RESEARCH FOUNDATION
IS ACCEPTING APPLICATIONS
FOR THE
2002 WYLIE SCHOLAR AWARD IN ACADEMIC VASCULAR SURGERY

The Wylie Scholar Award was established by the Pacific Vascular Research Foundation to honor the legacy of Edwin J. Wylie, by providing research support to outstanding vascular surgeon-scientists.

The Award is intended to enhance the career development of academic vascular surgeons with an established research program in vascular disease. The award consists of a grant in the amount of $50,000 per year for 3 years. Funding for the second and third years is subject to review of acceptable progress reports. This 3-year award is nonrenewable and may be used for research support, essential expenses, or other academic purposes at the discretion of the Scholar and the medical institution. The award may not be used for any indirect costs.

The candidate must be a vascular surgeon who has completed an accredited residency in general vascular surgery and who holds a full-time appointment at a medical school accredited by the Liaison Committee on Medical Educators in the United States or the Committee for the Accreditation of Canadian Medical Schools in Canada.

The applications are due by February 1, 2002, for the award to be granted July 1, 2002. Applications may be obtained by writing to: Pacific Vascular Research Foundation, Wylie Scholar Award, 3627 Sacramento Street, San Francisco, CA 94118.