Spinal cord arteriography: A safe adjunct before descending thoracic or thoracoabdominal aortic aneurysmectomy

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Objective: Spinal cord arteriography (SCA) often has been considered difficult, hazardous, and unreliable. In this report, we question these assumptions.

Patients: From August 1985 to June 2000, a total of 480 patients underwent 487 SCA procedures during diagnostic examination for 498 aneurysms, which included 159 that involved the descending thoracic aorta and 339 that involved the thoracoabdominal aorta. The underlying cause was degenerative disease in 288 cases, chronic dissection in 132 cases, and other causes in 78 cases.

Results: Major procedure-related complications occurred in six patients (1.2%) and included spinal cord complications in two patients, renal complications in two patients, and stroke in two patients. Puncture-site complications occurred in three patients (0.6%). Rupture of the aneurysm occurred within 3 days after SCA in two patients (0.4%). Two deaths (0.4%) were directly imputable to SCA. In 476 patients (97.7%), SCA was devoid of major complications. The Adamkiewicz’s artery was successfully located in 419 patients (86.0%) and arose from a left intercostal or lumbar artery in 323 patients (77.1%) and from between T8 and L1 levels in 361 patients (86.2%). On the basis of the extent of identification of spinal cord vasculature, the procedure was considered as a complete success in 321 patients (65.9%), as a partial success in 112 patients (23.0%), and as a failure in 54 patients (11.1%). Although the failure rates were comparable, the complete success rate was significantly higher in patients with degenerative rather than dissecting aneurysms (P < .001) and in patients with limited aneurysms (i.e., types 1, 2, and 3 versus type 4 descending thoracic aneurysms, P < .05; and types 3 and 4 versus types 1 and 2 thoracoabdominal aneurysms, P < .001).

Conclusion: SCA is a safe adjunct that warrants more widespread use in the management of descending thoracic or thoracoabdominal aortic aneurysms. (J Vasc Surg 2002;35:262-8.)

“Hopefully, some method of preoperative location of the origin of spinal cord circulation can be safely developed... that will include identification of important spinal and lumbar arteries that need to be spared or reattached.” —Crawford ES et al1

Spinal cord arteriography (SCA) as an adjunct before descending thoracic/thoracoabdominal aortic aneurysmectomy has been considered difficult, hazardous, and often unreliable.1–6 However, our experience shows that it can be safe and effective. The purpose of this report is to update preliminary data in a previous 45-case series published in 19897 with data from 487 SCA procedures that were performed before aneurysmectomy during a 15-year period.

PATIENTS AND METHODS

Patient population. From August 1985 to June 2000, 480 patients underwent 487 SCA procedures during preoperative examination before surgical treatment for descending thoracic or thoracoabdominal aortic aneurysm. There were 381 men (79.4%) and 99 women (20.6%), with a mean age of 61.1 ± 13.0 years. The underlying cause involved degenerative disease in 288 cases (57.8%), chronic dissection in 132 cases (26.5%), and other causes in 78 cases (15.7%).

Descending thoracic aortic aneurysms (n = 159; 31.9%) were classified according to our personal classification system8 as type 1 in 51 cases (19.5%); involvement of the aortic isthmus with distal extension limited to the middle segment of the descending thoracic aorta), type 2 in 29 cases (18.2%; involvement of the middle segment of the descending thoracic aorta), type 3 in 26 cases (16.4%; involvement of the distal segment of the descending thoracic aorta with proximal extension limited to the middle segment), and type 4 in 73 cases (45.9%; involvement of the whole descending thoracic aorta). Thoracoabdominal aneurysms (n = 339; 68.1%) were classified according to Crawford’s classification1 as type 1 in 82 cases (24.2%), type 2 in 111 cases (32.7%), type 3 in 88 cases (26.0%), and type 4 in 58 cases (17.1%).

Indications for spinal cord arteriography. During the study period, SCA was routinely used as a diagnostic adjunct before descending thoracic or thoracoabdominal aortic aneurysmectomy. The following three exceptions were the only ones made: 1, for patients who needed emergency treatment (n = 57); 2, for patients with type 1 descending thoracic aneurysms strictly limited to the isth-
mus (n = 34) or with some type 4 thoracoabdominal aneurysms (n = 45); and 3, for patients with microemboli or paraplegia/paraparesis as initial manifestations (n = 13). These last patients had been identified as having contraindications to SCA in our previous study. During the 15-year study period, 480 of the 629 patients (76.3%) with descending thoracic or thoracoabdominal aortic aneurysms underwent SCA.

**Spinal cord arteriography techniques.** The technique of catheterization and opacification of spinal cord vasculature has been described in detail elsewhere. The procedure consisted of selective catheterization, usually by the femoral route, followed by the manual injection of contrast material for the imaging of intercostal and lumbar arteries until the arteries that supplied the anterior spinal artery were identified. Only nonionic material was used, and the study was interrupted when the dose limit (6 mL/kg) was reached. If necessary, the study was resumed a few days later.

**Classification of results of spinal cord arteriography.** The goal of SCA was the delineation of the aortic branches to the anterior spinal artery (ie, Adamkiewicz’s artery, but also to the superior dorsal artery and even to the middle dorsal artery whenever the opacification of the Adamkiewicz’s artery did not allow the full visualization of the anterior spinal artery at the level of the aneurysm). The procedure was considered as a complete success when the entire anterior spinal artery at the level of the aneurysm was visualized, as a partial success when it was partly visualized, and as a failure when it was not visualized.

**RESULTS**

**Complications of spinal cord arteriography.** Major procedure-related complications occurred in six cases (1.2%) and included spinal cord complications in two cases, renal failure in two cases, and stroke in two cases. Puncture-site complications were observed in three cases (0.6%). Three of the major procedure-related complications (ie, both spinal cord complications and one kidney failure) occurred in our early experience before the underlying etiologic factors were identified as contraindications for SCA.

The first spinal cord complication involved a patient who had undergone SCA in 1987 for evaluation before the treatment of a chronic dissection of the descending thoracic aorta that had been diagnosed 4 weeks earlier after a transient episode of paraparesis. Paraparesis recurred during SCA and regressed completely within 4 days. The second patient underwent SCA in 1988 for the preoperative evaluation of type 3 thoracoabdominal aortic aneurysm as a result of degenerative disease. The presenting symptoms were blue-toe syndrome and kidney insufficiency. Paraparesis occurred during SCA and was followed with flaccid paraplegia a few days later. Three weeks later, subacute ischemia of the left lower extremity was observed with septic syndrome and finally acute renal failure. The patient’s general condition deteriorated, and he died on the 35th day after SCA.

Major renal complications were observed in two cases (0.4%). The first case was concurrent with spinal cord complications as described previously. The second case involved a patient with type 2 thoracoabdominal aortic aneurysm in 1993. Bilateral blue-toe syndrome and transient kidney insufficiency occurred during aortography. After a waiting period of 1 month for the allowance of the resolution of these embolic events, SCA was performed, which overrode the contraindication because the patient was at high risk for spinal cord complications. The procedure was complicated with colonic and renal emboli. Ischemic colitis responded well to medical management, but kidney insufficiency worsened and the patient needed permanent hemodialysis.

Stroke was observed in two patients (0.4%) with severe carotid artery lesions. The first patient had had a left hemispheric stroke 2 months earlier after the occlusion of the
left internal carotid artery. High-grade asymptomatic stenosis of the right internal carotid artery was successfully treated with endarterectomy with shunt placement. SCA was performed 4 days later. The next day, recurrent symptoms were observed in the region supplied by the left internal carotid artery and included massive aphasis and visual disturbances. The second patient with stroke had asymptomatic occlusion of the left internal carotid artery and a healthy right internal artery. Left hemispheric stroke occurred the day after SCA with aphasis and paresis of the right upper extremity and was followed with myocardial infarction.

The puncture-site complications (0.6%) included brachial occlusion, brachial arteriovenous fistula, and iliofemoral occlusion. All three were successfully treated at the same time as the aortic aneurysm.

Rupture of the aneurysm was observed within 3 days after SCA in two patients (0.4%). In one patient, surgical treatment was successful. The other patient died before surgical treatment could be undertaken.

The overall mortality rate in this series of 487 SCA procedures was 0.4% (n = 2). The causes of death were spinal and renal complications in one case and ruptured aortic aneurysm in the other case. The procedure was devoid of major complications in 476 patients (97.7%).

**Results of spinal cord arteriography.** The first attempt at SCA was a complete success in 284 cases (58.3%), a partial success in 116 cases (23.8%), and a failure in 87 cases (17.9%). In 67 of the partially successful procedures and in 30 of the failed procedures, the results were considered as final and no further attempt was made.

Second SCA procedures were undertaken in 49 cases that were considered as partial successes, which resulted in complete success in 15 cases and repeat partial success in 34 cases. A third attempt was successful in two of the 34 partially successful second attempts.

A second SCA attempt was undertaken in 55 of the 87 first-attempt failures. The outcome was a complete success in 16 cases, a partial success in 11 cases, and a repeat failure in 30 cases. A third attempt was undertaken in eight of the 30 repeat failures, which resulted in a complete success in four cases, a partial success in two cases, and a repeat failure in two cases.

In all, SCA was performed once in 381 cases (78.2%), twice in 96 cases (19.7%), and three times in 10 cases (2.1%). Including the results of the second and third attempts, SCA was a complete success in 321 cases (65.9%), a partial success in 112 cases (23.0%), and a failure in 54 cases (11.1%).

Tables I and II summarize the outcome of SCA in function of the anatomic features of the aneurysms. In the patients with descending thoracic aortic aneurysms (Table I), statistical analysis results showed that complete identification of spinal cord arteries was least likely in the patients with type 4 aneurysms that involved the whole descending thoracic aorta (P < .05) in comparison with the more limited type 1, 2, and 3 aneurysms. In the patients with thoracoabdominal aortic aneurysms (Table II), a complete success was least likely in type 1 and 2 aneurysms, with the most extensive involvement of the descending thoracic aorta as compared with type 3 and 4 aneurysms (P < .001). The failure rates for the two types of aneurysms were not statistically different (P value was not significant).

Table III summarizes the outcome of SCA in the function of the cause that underlies aneurysmal disease. Although the overall failure rates were the same (P value was not significant), the likelihood of a complete success was greater for aneurysms as the result of degenerative disease than for aneurysms as the result of chronic dissection (P < .001).

The Adamkiewicz’s artery was sought in 484 cases (99.4%) and was found in 419 cases (85.7%). The origin was located between the T7 and the L3 levels. It arose on the left side in 323 cases (86.2%; Fig 1). Visualization was direct through the injected intercostal or lumbar artery in 312 cases (74.5%; Fig 2) and indirect via anastomotic circulation in 107 cases (25.5%). Anastomoses were transverse with a contralateral intercostal or lumbar artery in 20 cases (18.7%; Fig 3), longitudinal with an immediately adjacent intercostal or lumbar artery in 78 cases (72.9%; Fig 4), and atypical from a posterior spinal artery (n = 5) or mammary artery (n = 4) in nine cases (8.4%). In 60 cases (14.3%), the Adamkiewicz’s artery was the only artery that supplied the anterior spinal artery at the superior dorsal, middle dorsal, and lumbar level.

The middle dorsal artery was identified in 61 cases. The origin was located between the T7 and the T11 levels. It arose from a left intercostal artery in 48 cases (78.7%; Fig 5). Visualization was direct through the injected intercostal artery in 49 cases (80.3%) and indirect via anastomotic circulation in 12 cases (19.7%). Anastomoses were transverse with a contralateral inter-

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**Table I.** Outcome of spinal cord arteriography in function of anatomic features (descending thoracic aortic aneurysms)

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<th>Complete success</th>
<th>Partial success</th>
<th>Failure</th>
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<tr>
<td>DTAA 1,2,3</td>
<td>73.3%</td>
<td>20.9%</td>
<td>5.8%</td>
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<td>DTAA 4</td>
<td>56.2%</td>
<td>34.2%</td>
<td>9.6%</td>
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DTAA, Descending thoracic aortic aneurysm.
*P < .05.
†P value was not significant.

**Table II.** Outcome of spinal cord arteriography in function of anatomic features (thoracoabdominal aortic aneurysms)

<table>
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<th>Complete success</th>
<th>Partial success</th>
<th>Failure</th>
</tr>
</thead>
<tbody>
<tr>
<td>TAA 1-2</td>
<td>50.8%</td>
<td>34.7%</td>
<td>14.5%</td>
</tr>
<tr>
<td>TAA 3-4</td>
<td>85.6%</td>
<td>4.1%</td>
<td>10.3%</td>
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TAA, Thoracoabdominal aortic aneurysm.
*P < .001.
†P value was not significant.
costal artery in three cases (25.0%), longitudinal with an adjacent intercostal artery in six cases (75.0%), and atypical in three cases (25.0%).

The superior dorsal artery was sought in 323 cases (66.3%) and was located in 135 cases (41.8%). The origin was located between the T3 and the T8 levels. It arose from a left intercostal artery in 93 cases (69.9%; Fig 6). Visualization was direct through the injected intercostal artery in 112 cases (83.0%; Fig 7) and indirect through another intercostal artery in 21 cases (15.6%). In the remaining two cases (1.4%), the superior dorsal artery arose directly from the vertebral artery. Anastomoses were transverse with a contralateral intercostal artery in six cases (28.6%), longitudinal with an immediately adjacent intercostal artery in nine cases (42.8%), and atypical in six cases (28.6%). In three cases (2.2%), the superior dorsal artery was the only artery that supplied the anterior spinal artery at the superior dorsal, middle dorsal, and lumbar level.

**DISCUSSION**

This is the largest series of SCA procedures before aneurysm repair in the literature. Previous reports by Heinemann et al., Williams et al., and Bachet et al. contained 46, 47, and 36 cases, respectively. The results of this experience clearly show that SCA is safe. In 487 procedures, there were only eight major procedure-related complications (1.6%), including two that were fatal (0.4%). Heinemann et al. and Bachet et al. observed no procedure-related complications. Williams et al. reported one probable case of pancreatic and renal atherosclerotic embolism that needed postponement of surgical repair for 3 months, one case of transient paresthesia of the lower extremities during contrast injection, and one ruptured aneurysm 2 days after SCA that ultimately led to death 1 day after surgical repair.

These findings show that the risk of SCA is minimal in properly selected patients provided that contraindications are respected. We have observed no further spinal cord complications since contraindicating patients with recent history of paraplegia/paraparesis or peripheral emboli.

In our study, the success rate for the identification of the Adamkiewicz’s artery was 85.7% (419 of 484 attempts) as compared with 55%, 65%, and 77%, respectively, in the three previously mentioned studies. The main difference between our study and previous studies is that we were attentive to the mode of opacification of the Adamkiewicz’s artery (ie, direct or indirect through anastomoses) and to the location of other aortic branches that might contribute to spinal cord vascul-
larization (ie, the superior dorsal and middle dorsal arteries). Our preliminary results\textsuperscript{7} showed a significant correlation between these two anatomic factors and the risk of postoperative spinal cord complications.

The Adamkiewicz’s artery was opacified indirectly with anastomoses in 107 of 419 cases (25.5%). In most cases, the anastomosis was longitudinal to an immediate adjacent ipsilateral intercostal or lumbar artery. However, in some cases, the anastomosis was either transverse with the contralateral intercostal or lumbar artery or atypical from a posterior spinal artery or mammary artery. The superior dorsal artery was opacified indirectly with anastomoses in 21 of 135 cases (15.6%), with longitudinal anastomoses from an immediately adjacent ipsilateral intercostal artery being observed in most cases.

Attempts at visualization of middle dorsal or superior dorsal arteries were less frequently successful than when we attempted to delineate the Adamkiewicz’s artery. Possible explanations are that aortic disease may be more severe at the upper thoracic level, especially when the result of chronic dissection, and that some superior dorsal arteries may arise from the first intercostal arteries rather than directly from the aorta.

In general, our findings were in agreement with the data that were presented in recent anatomic descriptions of spinal cord vasculature.\textsuperscript{14-18} This was notably the case with regard to the origin of the Adamkiewicz’s and superior dorsal arteries. These anatomic descriptions imply that SCA should not be considered as a complete success after the delineation of the Adamkiewicz’s artery alone. The superior dorsal artery and eventually the middle dorsal artery must also be identified. As expected, there was a statistically greater chance of completely successful SCA in patients with limited aneurysms and in patients with aneurysms that were the result of degenerative disease versus chronic dissection.

The results of our preliminary study\textsuperscript{7} showed that the risk of postoperative spinal cord complications was much higher in patients in whom SCA was a partial success or failure. We are currently evaluating the impact of SCA on our recent surgical series (1991 to 2000) in which a standardized protocol was used that included the routine use of distal aortic perfusion and the selective use of deep hypothermic circulatory arrest.

However, the routine use of SCA does not completely eliminate the risk of spinal cord complications during surgery for aneurysms of the descending thoracic aorta or thoracoabdominal aorta. Even if SCA is successful, intraoperative identification of arteries may be difficult. Spinal cord complications can also be caused by several other problems. The revascularization of the spinal cord arteries may be technically problematic in the case of extensive aortic disease or calcification. Prolonged clamping time can cause spinal cord ischemia in patients with no collateral spinal cord arterial supply. Thromboembolic complications can occur from the immediately adjacent aorta. Spinal cord ischemia can result from a variety of causes, and SCA addresses only one mechanism. The only reliable method for the assessment of the true benefit of SCA in terms of prevention of spinal cord complications would be a con-
trolled prospective study that compares the use of surgery with SCA-guided reimplantation with conventional surgery with the reimplantation of all the patent arteries between the T7 and L1 level. Because of the difficulties involved, the likelihood that such a study can ever be conducted is low. On the basis of our experience, we conclude that SCA is a safe adjunct that deserves more widespread use in the management of descending thoracic or thoracoabdominal aortic aneurysm.

REFERENCES


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DISCUSSION

Dr John E. Connolly (Irvine, Calif). I’d like to commend Dr Kieffer on his continued efforts to find a safe way to selectively catheterize and identify the blood supply to the spinal cord to minimize paraplegia when operating on descending thoracic and thoracoabdominal aortic aneurysms. I’d like to ask if you are aware of this CT technique and what you think of its possibilities?

Dr Edouard Kieffer. In fact, the technical aspect of the problem is very important, and we had the luck of working with a very experienced neuroradiologist who had done a thousand spinal cord arteriographies before he gave him one patient.

Helical CT, I’m not aware of this technique. I just want to see what it gives. I’m ready to accept the noninvasiveness of the technique, which is probably more important than any other thing.

And finally, your technique of revascularization of the distal intercostal arteries in thoracic aneurysms, yes, of course, it’s important, but it’s not the main problem. The main problem is for thoracoabdominal types 1 and 2.

Dr G. Melville Williams (Baltimore, Md). I rise to just congratulate my colleague, Professor Kieffer, for another elegant
presentation. We're not as successful percentagewise in identifying the artery of Adamkiewicz as he is, finding it in about 55% of about 230 exams that we have now performed. What’s striking to me, however, is the rich collateral supply and the variability in the size of the anterior spinal artery which makes me feel that if we rely on thin-cut CT scans, we’re going to miss small ones. We’ve tried this, in fact, and have not the success that Dr Connolly has told us about in trying to find this artery. We agree with Dr Kieffer that when this artery is identified, there are techniques available now to get it back into circulation. And we have had, up until about a year ago, no incidence of paraplegia when the artery has been identified, and we’ve gotten it into the circulation. We recently had one instance that is the exception to the rule.

Dr Kieffer. There is a team in Germany who has performed spinal cord arteriography, but the numbers were small and the conclusions were the same as in our study. I’m aware of the fact that identifying the spinal cord arteries may be a protection against paraplegia, but I want to reiterate that there are other causes than the spinal cord arteries to explain the spinal cord complications, including reperfusion injury, ischemia during clamping, and embolism.