From the Society for Vascular Surgery

Staged endovascular repair of thoracoabdominal aortic aneurysms limits incidence and severity of spinal cord ischemia

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Objective: **Neurologic dysfunction remains a persistent complication of extensive aortic repair owing to disruption of the spinal collateral network. We hypothesized that staged repair might mitigate the incidence and severity of this spinal cord ischemia (SCI).**

Methods: **We conducted a retrospective cohort study of patients undergoing a Crawford type II repair of a thoracoabdominal aortic aneurysm between January 2008 and July 2013. Baseline demographics, incidence of prior aortic surgery, comorbidities, and outcomes were prospectively recorded. Staged repair was defined as intentional completion of the endovascular repair as two temporally separate procedures, referred to as a two-stage repair. Extent of aortic cover was calculated by three-dimensional imaging and reported as the proportion of the aorta covered between the left subclavian artery and the aortic bifurcation. Primary outcome measures were incidence and severity of SCI and mortality.**

Results: **The study included 87 patients, divided into the following subgroups: single-stage repair (n = 32; repair in a single procedure, without prior aortic surgery), two-stage repair (n = 27; repair in two separate procedures, without prior aortic surgery), and unintentionally staged repair (n = 28; those with prior aortic surgery, without an intention to stage). Median time between stages was 5 months (range, 1-60 months). All groups were equivalent in terms of demographics and risk factors; however, the staged group had significantly greater proximal aortic cover ($P = .001$). The overall rates of SCI in the nonstaged and staged groups were 37.5% (12 of 32) and 11.1% (3 of 27), respectively ($P = .03$). Furthermore, all neurologic injuries in the staged group were temporary. The 30-day survival in the single-stage, two-stage, and unintentionally staged repairs was 18.8%, 0%, and 10.7%, respectively ($P = .52$).**

Conclusions: **Staged repair appears both to protect against SCI and to enhance overall survival in extensive aortic repair. (J Vasc Surg 2015;61:347-54.)**

Open surgical thoracoabdominal aortic aneurysm (TAAA) repair offers patients a durable solution for this devastating disease, provided they can tolerate the morbid procedure. Initial reports of the successful repair of TAAA were soon followed by the recognition that such extensive surgery was associated with an increased incidence of postoperative neurologic dysfunction.[1,2] Over time, the development of protective measures, such as moderate hypothermia, distal bypass, and spinal drainage, mitigated these effects in part. However, maintenance of spinal perfusion, in the form of intercostal reimplantation, has been shown to be a powerful determinant of a positive outcome.[3,4]

Endovascular repair of TAAA affords high-risk patients a therapeutic solution.[5] The absence of aortic cross-clamping and the avoidance of a thoracotomy, among other benefits, conspire to lessen the insult associated with open repair. However, despite these advances, the incidence of postoperative neurologic dysfunction remains stubbornly high. Rates of spinal cord ischemia (SCI) after endovascular repair of TAAA have been reported as high as 20%.[6] Device length, extent of aneurysm repaired, and occlusion of spinal collaterals such as the left subclavian artery or hypogastric artery were shown to be important contributors to the development of postoperative spinal dysfunction and clinical outcomes.[7,8] In spite of the many benefits of endovascular surgery, options are limited with regard to maintenance of perfusion of any excluded intercostal or lumbar vessels.

A combination of clinical and experimental work in the last decade has served to further elucidate the spinal perfusion network and the relative importance of the different contributors. What has emerged is the concept of a collateral network that can potentially lessen the impact of spinal ischemia if it is optimized.[9] This collateral network may behave in a compensatory manner, similar to other vascular beds, and maintain perfusion pressures when contributors are excluded. Separating the ischemic insult into two lesser procedures may facilitate the remaining perfusing elements to compensate and so maintain function. We hypothesized that staging of extensive thoracoabdominal repairs in this

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fashion may lessen the incidence and severity of spinal ischemia. The aim of this investigation was to evaluate the outcomes for patients undergoing endovascular TAAA repair, comparing outcomes between those who were repaired at one setting and those who were repaired in a staged fashion.

METHODS

A retrospective cohort study of patients undergoing endovascular repair of a Crawford type II TAAA between January 2008 and July 2013 was performed. This analysis represents a subset of patients who underwent a fenestrated or branched repair of a TAAA between 2001 and the present and are maintained in a prospective database as part of a physician-sponsored Investigational Devices Exemption trial (NCT00583050). The constituent patients have been well described previously but briefly include those who, by virtue of their comorbid conditions, are considered at high risk for conventional repair.[10] Recorded variables include clinical, operative, and imaging data for each patient as well as outcomes and any secondary interventions performed. Operative strategy was recorded with regard to those who underwent either primary repair or repair in a staged fashion. After device implantation, patients were physically evaluated and imaged at 1 month and 6 months and thereafter at yearly intervals. Informed consent was obtained from each patient before surgery, and the trial was approved by the Cleveland Clinic Institutional Review Board (IRB #12-994).

The default strategy for total endovascular repair of TAAA disease was stent insertion and achievement of aneurysmal exclusion in a single procedure. It was the recognition that extensive aortic cover exacerbated the risk of postoperative paraplegia that led to the decision to begin staging of endovascular TAAA in an effort to decrease the insult and to give the spinal perfusion network an opportunity to collateralize. Patients who were staged fell into two separate categories, those who were intentionally staged (two-stage repair) and those who had prior aortic repair (unintentional staging). Intentional staging of the procedure was performed by initial placement of a thoracic aortic endograft, covering the aorta from the proximal seal zone to just above the level of the most proximal visceral branch vessel to be incorporated in the fenestrated or branched repair. Repair in this manner leads to a type Ib endoleak, which is then excluded after insertion of the visceral segment device following an interval of approximately 2 to 3 months (this represents the ideal; in practice, the interval is often longer because of scheduling difficulties or the patient's preference). The aorta was defined as that segment from the left subclavian origin to the aortic bifurcation; therefore, elephant trunk grafts performed for concomitant arch disease were not considered as a staged aortic repair in this study. For the purposes of this paper, staged repair refers to an operative strategy as outlined before; single-stage repair describes the complete aneurysmal exclusion with a fenestrated or branched endograft at one single, operative time point.

The decision to offer an individual patient a staged repair was at the discretion of the operating surgeon. However, the trend in recent years has been to stage the majority of the type II repairs. Few type III repairs and no type I or IV repairs were staged, and consequently those repairs have been excluded from this analysis. It has always been our practice to categorize patients on the basis of the repair rather than the aneurysm; thus, a proportion of the type II patients would have had type III aneurysms but required aortic cover above T6 to achieve a durable repair.

The steps involved in device selection and insertion have been described previously.[10] The tenants of multimodal optimization were used to maximize spinal perfusion. Briefly, this consisted of maintenance of a postoperative mean arterial pressure above 85 mm Hg, avoidance of fluid overload, and perioperative use of a spinal drain to minimize intrathecal pressures as previously described.[5,8]

SCI was defined as an objective deterioration in motor function in the postoperative period before discharge (no patient was admitted after discharge with a new loss of function attributable to the repair). Patients were examined at least twice daily by a member of the clinical team and more frequently if indicated. All complications were recorded prospectively by a research nurse on a standardized pro forma. Imaging confirmation of a spinal infarct was not used to make the diagnosis; however, any new incident of neurologic dysfunction was investigated with a computed tomography (CT) brain scan to exclude intracerebral hemorrhage as a contributor. SCI was scored on a 3-point scale (Supplementary Table, online only) and described as permanent or temporary (temporary defined as improvement of one full grade before discharge) and in terms of timing at onset (immediate, in the first 24 hours, or delayed, thereafter). The primary outcome measure was the incidence of spinal ischemia. Secondary outcomes included the severity and duration of any neurologic dysfunction suffered, cardiorespiratory and renal morbidity, and both 30-day and overall mortality.

Clinical information, inclusive of baseline demographics, comorbid conditions, and outcomes, was recorded for each patient. Of particular interest was the prevalence of prior aortic surgery, as we hypothesized that this may function as a type of unintentional staging. Therefore, patients were stratified both by repair type and by the presence of prior aortic repair (defined, as before, as open or endovascular aortic replacement between the left subclavian artery and aortic bifurcation). Operative factors, such as procedural time, fluoroscopy time, volume of contrast material, and procedural success, were also noted. Preoperative and postoperative CT angiography was used to calculate the proportion of aorta covered by the device, and this measurement was then used along with the Crawford classification as a descriptor. Arterial contrast CT imaging was imported onto a three-dimensional workstation (TeraRecon, San Mateo, Calif) and a semiautomated centerline of flow created. All imaging analysis and measurements were performed on this workstation. The log-rank test (Mantel-Cox) was used to compare survival data. Student *t*-test