Research Highlight

Open surgical repair of thoracoabdominal aneurysms - the Massachusetts General Hospital experience

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Introduction

The modern era of surgical management of thoracoabdominal aneurysms (TAA) began with the pioneering work of E. Stanley Crawford (1); this benchmark series reported an operative mortality of 10% with an incidence of spinal cord ischemia (SCI) of 16%, some 50% of which were total paraplegia. Over a 20 year period until 2006, TAA repair at our institution (2) was predominantly performed using a simplified clamp and sew approach in accordance with Dr. Crawford's teachings which emphasized operative expediency and technical efficiency (2). Management of TAA during this time was typically performed without use of distal perfusion techniques. Adjunct use included routine cerebrospinal fluid (CSF) drainage (3,4), aggressive intercostal re-implantation (3,5,6), regional hypothermia for spinal cord protection (7,8), infusion of hypothermic renal preservation fluid for prevention of renal failure, and in-line mesenteric shunting (9) to reduce complications resulting from visceral ischemia. Using this approach we achieved favorable results with an overall operative mortality of 8% (6% elective and 13% urgent) with significant SCI in 8% of patients (2).

Largely driven by the apparent failure of epidural cooling to drive SCI to less than 5%, we modified operative management of TAA in recent years in an effort to further reduce spinal cord complications. As our experience has shown (10) that patients with type IV TAA can safely be managed with a simplified clamp/sew approach with favorable results, this evolution in operative strategy has been exclusively implemented in management of patients with extents I-III TAA. In essence the rationale exploited the collateral network concept (11-13): we adopted routine use of distal aortic perfusion (DAP) via left atrial to femoral bypass to support the collateral circulation to the spinal cord during the period of aortic cross clamp application. Additionally, intra-operative motor evoked potential (MEP) monitoring (14,15) has afforded the ability to dynamically assess spinal cord ischemia during aneurysm reconstruction. As a result, we have abandoned aggressive intercostal re-implantation in favor of a selective MEP driven re-implantation strategy. Clinical outcomes resulting from this evolution in operative strategy for extents I-III TAA have recently been published and are further highlighted herein (16).

Methods

Data for all thoracic aortic procedures performed at Massachusetts General Hospital (MGH) are prospectively entered into our institutional Thoracic Aortic Center (TAC) database. TAC data is independently verified and validated by hospital employed clinical nurses who maintain data integrity. Using the TAC dataset, we performed a retrospective analysis of all consecutive types I-III repairs performed at the MGH from September 1989 through December 2009. Prior to July 2006, extents I-III TAA were repaired with a predominantly clamp and sew approach with the aforementioned protective adjuncts utilized. During this era distal aortic perfusion was seldom utilized (~10%), except in patients with significant renal dysfunction or those in whom the proximal reconstruction was anticipated to be technically challenging. Intercostal re-implantation within the critical T9-L1 region, when technically feasible, was routinely performed in accordance with both published literature, and our own observations

Table 1 Patient demographics and clinical features

Feature	Clamp & Sew (n=384)	DAP & MEP (n=60)	P-value
Male	44.0	51.7	0.329
Age (yrs) Mean ± SD	70.9±9.7	63.6±12.8	<0.001
Crawford I	32.0	46.7	
II	18.2	15.0	0.096
III	49.7	38.3	
CVA	7.8	3.3	0.285
Hypertension	88.8	88.3	0.829
CAD	46.9	16.7	<0.001
Smoking	82.8	76.7	0.278
COPD	20.6	21.7	0.864
CRI	10.1	8.3	0.817
Dissection	18.9	33.9	0.015

DAP = distal aortic perfusion; MEP = motor evoked potential monitoring; CVA = cerebrovascular accident; CAD = history of coronary artery disease; COPD = chronic obstructive pulmonary disease; CRI = chronic renal insufficiency

Table 2 Procedural details

Technical detail	Clamp & Sew (n=384)	DAP & MEP (n=60)	P-value
OR time (min) Mean ± SD	323.7±98.1	416.5±91.8	<0.001
Urgent operation	24.4	13.3	0.068
In-line mesenteric shunt	36.9	26.7	0.176
DAP	11.2	100	<0.001
MEP	0	100	<0.001
Total clamp (min) Mean ± SD	75.4±28.9	75.1±39.4	0.961
Visceral ischemia (min) Mean ± SD	49.7±16.4	40.7±34.3	0.016
Total renal ischemia (min) Mean ± SD	62.5±20.8	42.1±31.5	<0.001

OR = operating room; DAP = distal aortic perfusion; MEP = motor evoked potential monitoring

that sacrifice of T9-L1 intercostal vessels was a correlate of SCI (5,6). Detailed descriptions of the technical conduct of TAA repair (clamp/sew and DAP/MEP) have been published elsewhere (7,16).

The impact of demographic factors and clinical features on peri-operative outcomes were studied. Chronic renal insufficiency (CRI) was defined as a baseline serum creatinine greater than 1.5 mg/dL. Coronary artery disease (CAD) was defined as a history of myocardial infarction, positive cardiac stress test, or previous percutaneous or open surgical coronary artery revascularization. Pulmonary disease was determined by pre-operative pulmonary function testing in the majority of patients. Aneurysm related features included aneurysm type, pathology, and urgent *vs*. elective repair. An urgent operation was defined as symptomatic presentation necessitating Intensive care unit (ICU) admission for invasive hemodynamic monitoring and operative reconstruction within 48 hours of admission.

Statistical analysis

All demographic data and clinical features are presented as percent prevalence in the study population. All mean data are presented as mean ± standard deviation (SD). Statistical analysis was performed by using two-tailed t tests for continuous variables and chi-square analysis for categorical data. Multivariable regression analysis was performed to identify predictors of the composite endpoint of death and spinal cord ischemia. Results with a P<0.05 were considered statistically significant. Statistical analysis was performed using SAS version 9.2 (Cary, NC).

Results

Four hundred and forty-four patients underwent extents I-III TAA repair over the study period, including 384 patients treated with clamp/sew and 60 patients with the modified operative strategy using DAP/MEP. Clinical and demographic features are summarized in *Table 1*. Patients treated with DAP/MEP were younger and more likely to harbor aneurysms of chronic dissection etiology. Technical features of operative conduct are presented in *Table 2*. Patients treated with DAP/MEP were more likely to have lower visceral ischemia and total renal ischemia times, despite having have longer operative times. Peri-operative outcomes are summarized in *Table 3*. Operative morality (30-day), permanent SCI and the composite endpoint of permanent SCI and death were all significantly lower in patients treated with DAP/MEP. On multivariable logistic regression modeling, DAP/MEP use was independently associated with a significant reduction in the composite outcome of perioperative SCI/death (OR 0.1, 95% CI: 0.012-0.67; P=0.01).

Table 3 Peri-operative outcomes

Outcome	Clamp & Sew (n=384)	DAP & MEP (n=60)	P-value
Post-op death	9.9	1.7	0.046
LOS (days) Mean ± SD	21.6±23.6	19.1±12.5	0.410
Permanent SCI	11.7	0	0.002
SCI/Death	19.0	1.7	<0.001
Any cardiac complication	17.2	20.3	0.581
Any pulmonary complication	54.3	44.4	0.191
Renal failure with HD	11.5	1.7	0.019

DAP = distal aortic perfusion; MEP = motor evoked potential monitoring; LOS = length of stay; SCI = spinal cord ischemia; HD = hemodialysis

Discussion

Thoracoabdominal aortic (TAA) aneurysm repair has historically been associated with significant morbidity and mortality (1), in particular in administrative database studies; however recent large, single center reports have presented markedly improved results most notably with respect to SCI (17-21). This improvement in outcomes reflects the impact of cord protection strategies adopted over time (22). On the contrary, patients undergoing extent IV TAA repair have uniformly had a very low risk of SCI independent of variations in operative technique or adjunct use (18,23-26). Our stance on operative management of extent IV TAA has continued to emphasize operative expediency and efficiency, using a standardized clamp/sew approach. Using this approach we have achieved favorable results in the management of extent IV TAA, with an operative mortality rate of 2.8% in a recently published series of 179 repairs, more than 90% of which were repaired using a standardized technique (10). Our results were also notable for a favorable SCI rate of 2.2% without routine use of cord protective strategies such as CSF drain (<15%) or epidural cooling (12%). Regression analysis of the data from that series showed that technical factors in aneurysm reconstruction and protective adjuncts were not predictive for development of SCI, strongly suggesting that a continued clamp/sew approach in patients with extent IV TAA is appropriate.

Finite improvements in SCI and mortality following repair of more complex TAA in our hands prompted an evolution in operative strategies for management of extent I-III TAA. Our current understanding was predominantly influenced by the concept of the spinal cord's collateral network as originally described by Griepp *et al.* (11,12). Recent magnetic resonance angiography studies have elegantly demonstrated the existence of a robust network of collateral vessels which reconstitute the great radicular artery via intersegmental collaterals emanating from distal segmental arteries (many vertebral levels away) and even more distal pelvic and hypogastric branches (13). The existence of such collateral vessels argues in favor of assisted circulation techniques to support perfusion of these vessels intra-operatively during cross clamp application. Clinical and physiological support for this has been provided using intra-operative monitoring to detect spinal cord ischemia. Jacobs *et al.* clinically observed that in patients with complete occlusion of critical and distal intercostal vessels, MEPs were highly dependent upon maintenance of pelvic perfusion using atrial-femoral bypass with rapid deterioration in MEP amplitudes with temporary discontinuation of the bypass circuit during distal clamp application (17,27). Further clinical support for use of distal perfusion has been provided by Safi *et al.* who have reported on the reduction of SCI and mortality following institution of a combined adjuncts comprised of CSF drainage, passive hypothermia (32-34 ℃) and distal aortic perfusion (28). Using this adjunct combination these investigators effectively reduced overall SCI rates to 3.3%, with the majority of benefit derived from reduction of SCI in TAA types I and II from 31% to 9% (29).

The current review highlights progressively improved outcomes coincident with the evolution in operative strategy for extents I-III TAA. Although the benefit of an expedient operation seems intuitively logical, these data show that we have achieved significant improvement in operative mortality and SCI (1.7% combined) despite longer operating times, higher blood turnover, use of sequential aortic cross clamp application, and limited (~10%) intercostal re-implantation (16). Our comparative results suggest that our current techniques utilizing DAP to support the spinal cord's collateral network and MEP monitoring to dictate selective intercostal re-implantation is the favored approach in treating patients with extents I-III TAA.

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