Open arch reconstruction in the endovascular era: Analysis of 721 patients over 17 years

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Objective: Recent advancements in thoracic endovascular aortic repair, such as branched endografts or hybrid debranching/thoracic endovascular aortic repair, have extended the option of endoluminal therapy into the realm of the aortic arch. A contemporary assessment of open arch repair to provide long-term data for comparative analysis for these newer therapies is timely, warranted, and presented in this article.

Methods: Since the inception of our thoracic endovascular aortic repair program in 1993, 721 patients (mean age of 59.3 years, 68.9% were male) have undergone median sternotomy and open arch reconstruction with hypothermic circulatory arrest. Extended arch repair was performed in 42.7% with construction of bypasses to the innominate (296 patients), left carotid (216 patients), and subclavian (75 patients) arteries or elephant trunk procedures (42 patients). Concomitant aortic valve or aortic root replacement was required in 403 patients, and root reconstruction was required in 222 patients. Retrograde (641 patients) or antegrade (400 patients) cerebral perfusion was used for neuroprotection during hypothermic circulatory arrest. The operative procedure was urgent or emergency in 316 patients (43.8%) and included repair of type A dissection in 284 patients (39.3%). A total of 111 patients (15.4%) had undergone prior cardiac surgery. Primary outcomes in this study were early and late mortality. Follow-up was 100% complete (mean, 52.6 months).

Results: Thirty-day morbidity included death (36 patients [5%]), stroke (34 patients [4.7%]), and permanent dialysis (14 patients [1.9%]). Independent predictors of early mortality included advancing age, prolonged bypass times, and impaired ejection fraction (all $P < .05$). Actuarial survival at 10 years was 65%. Independent predictors of late mortality included advancing age, prolonged lower body circulatory arrest times, and increasing creatinine (all $P < .05$). By Kaplan–Meier analysis, 10-year survival was significantly reduced after operative procedures for type A dissection (non–type A 69.1% vs type A 58%, $P = .003$). Freedom from aortic reoperation (any segment) was 72.6% at 10 years.

Conclusions: Open aortic arch repair can be accomplished with excellent early and late results. These outcomes provide objective data for comparison and suggest that newer endovascular therapies should be evaluated first in high-risk groups, such as those with advanced age or impaired renal function before broader application in all patients. (J Thorac Cardiovasc Surg 2011;141:1417-23)

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In the century since Sir William Osler remarked that ‘‘there is no disease more conducive to clinical humility than aneurysm of the aorta,’’ dramatic advances have occurred in the field of aortic surgery. After the pioneering work by DeBakey and colleagues in 1957,[1] mortality for arch reconstruction exceeded 25%, with cause of death often secondary to neurologic complications. The introduction of deep hypothermic circulatory arrest (HCA) by Griepp and colleagues[2] simplified the operative approach and established a safe strategy for neuroprotection. Seminal work by Svensson and associates[3] in 1993 demonstrated that these techniques used in 656 patients could result in death and stroke rates of 10% and 7%, respectively.

Since this landmark report, the introduction of endovascular techniques has revolutionized the therapy of thoracic aortic disease.[4-7] Although initially applied to degenerative aneurysms confined to the abdominal and descending thoracic aorta (thoracic endovascular aortic repair [TEVAR]), recent work has extended the use of this approach to the arch aorta.[4,5] Moreover, in an effort to reduce the perceived morbidity associated with HCA, complex extra-anatomic arch vessel bypass and endovascular repair, that is, debranching procedures and evolving technology including branched endografts, have extended TEVAR into the ascending aorta.[7,8] The long-term results of endovascular repairs with or without debranching are still unclear. It is in this context that a contemporary analysis of open aortic arch reconstruction focusing on both early and

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Disclosures: Authors have nothing to disclose with regard to commercial support.

Read at the 90th Annual Meeting of The American Association for Thoracic Surgery, Toronto Ontario, Canada, May 1–5, 2010.

Received for publication May 4, 2010; revisions received Feb 10, 2011; accepted for publication Feb 18, 2011; available ahead of print April 4, 2011.

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0022-5223/$36.00

doi:10.1016/j.jtcvs.2011.02.020

Abbreviations and Acronyms

ACP	= antegrade cerebral perfusion
CI	= confidence interval
HCA	= hypothermic circulatory arrest
HR	= hazard ratio
OR	= odds ratio
RCP	= retrograde cerebral perfusion
TEVAR	= thoracic endovascular aortic repair

late outcomes is warranted. The study period chosen in this study reflects the endovascular era at the University of Michigan, which commenced in 1993.

MATERIALS AND METHODS

This study was approved by the institutional review board of the University of Michigan Hospitals (study 2003-0128). Informed consent requirements were waived for this study.

A retrospective analysis of data from all patients admitted to the University of Michigan Hospitals from 1993 to 2009 who underwent aortic replacement was performed. Criteria for entry into the study cohort consisted of (1) approach via a median sternotomy; (2) resection into the arch aorta (ie, exclusion of open distal anastomosis without arch reconstruction); and (3) use of deep HCA (eg, exclusion of patients undergoing great vessel bypass for obstructive arch disease). With the use of these inclusion criteria, 721 consecutive patients constituted the study cohort. A combination of clinic and hospital records, data from the prospectively collected Society of Thoracic Surgeons database, imaging studies, and query of the National Death Index were used to obtain early and long term information.

Operative Technique

After median sternotomy and institution of cardiopulmonary bypass, patients were cooled to 18°C nasopharyngeal and bladder temperature with the maximum temperature gradient between perfusate and body temperature kept at less than 10°C (for both cooling and later rewarming). During this time, root reconstruction was initiated if necessary. Neuroprotective adjuncts, including 25 g mannitol, 1 g methylprednisolone, and 1 g thiopental, were administered just before institution of HCA. The aorta was then opened, and the site of distal anastomosis was identified. Retrograde cerebral perfusion (RCP) was initiated at this time in 641 patients (89%), with flows of 500 to 800 mL/min titrated to a central venous pressure of 35 mm Hg. With proximal hemiarch resection, HCA with RCP alone was often used, and RCP then was discontinued only after reinstitution of cardiopulmonary bypass to prevent air embolism into the brain. If prolonged HCA times were expected either on the basis of pathology or the need to extend arch resection to include great vessels, antegrade cerebral perfusion (ACP) was used at flow rates of 750 to 1000 mL/min titrated to keep the pressure in the right radial arterial line at 80 mm Hg by selective cannulation of the innominate and left carotid arteries or by axillary arterial perfusion with left carotid artery selective cannulation. In this instance, RCP was then discontinued only after initiation of ACP to prevent air embolism. Rewarming was initiated after completion of the open distal anastomosis, and flow was restored to the lower body. Great vessel reimplantation was performed as an island until 2001, after which each vessel was bypassed separately using a customized Dacron graft with multiple prefabricated side branches as previously described. The graft was then sized to an appropriate length, and a proximal anastomosis was performed. When normothermic, the patient was weaned from cardiopulmonary bypass as tolerated.

Statistical Methods

Early outcomes of interest included 30-day or in-hospital rates of mortality, stroke, and renal failure requiring dialysis. The primary late outcome of interest was survival time and vital status. Early mortality was defined as that occurring within 30 days of operation or in-hospital death. Late mortality was defined as that occurring thereafter. Follow-up was 100% complete up to April 2010 for the primary outcome of late mortality with a mean of 52.6 ± 39.9 months.

Data were analyzed using SPSS (SPSS Inc, Chicago, Ill). All data are expressed as mean ± standard deviation where applicable. Dichotomous variables were evaluated using chi-square analysis, and continuous variables were evaluated using independent *t* tests. Multivariate models (binary logistic regression for early outcomes and Cox proportional hazards for late outcomes) were constructed using a forward conditional process to identify factors that were independently associated with each of the outcomes of interest. The factors used in the multivariate analysis included those with a P value of 0.1 or less on univariate analysis. Results were expressed with odds ratios (ORs) or hazard ratios (HRs) with 95% confidence intervals (CIs). Survival was analyzed by Kaplan–Meier methods, with comparison of survival curves performed with the log-rank test.

RESULTS

The mean age of the study cohort was 59.3 ± 13.9 years (68.9% were male). Demographics and comorbidities are listed in Table 1. Indications for intervention included type A dissection in 284 patients and fusiform aneurysm in 416 patients. Arch repair was performed in the reoperative setting in 111 patients (15.4%); details regarding prior aortic or cardiac procedures are listed in Table 1. The procedure was elective in 404 patients (56%), urgent in 128 patients (17.8%), and emergency in 188 patients (26.1%).

Early Results

Early mortality was seen in 36 patients (5.0%). By multivariate analysis, older age (P = .001; OR, 1.07; CI, 1.0–1.2), lower ejection fraction (P = .02; OR, 0.97; CI, 0.95–0.99), prolonged cardiopulmonary bypass (P < .0001; OR, 1.01; CI, 1.007–1.02), and HCA time (P = .02; OR, 1.03; CI, 1.004–1.05) were independently associated with early mortality. In an attempt to identify whether era of the operative procedure affected mortality, the entire study period was divided into 2 segments: era 1 (1993 to March 2005, n = 316), representing the initial time when endovascular repair (TEVAR) was available only on a limited basis at the University of Michigan Cardiovascular Center for compassionate use or as part of Food and Drug Administration-sponsored clinical trials; and era 2 (April 2005–2009, n = 369), when TEVAR was widely available. Although the mortality rates were different on univariate analysis (era 1: n = 23, 7.3% vs era 2: n = 13, 3.5%, P = .04), multivariate analysis did not identify era of operation as an independent risk factor for death.

Stroke was identified in 34 patients (4.7%). Univariate predictors of postoperative stroke included the history of coronary artery disease, chronic obstructive pulmonary disease, reduced ejection fraction or elevated creatinine, urgent or emergency operative status, repair of acute type A

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