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The elephant trunk is freezing: The Hannover experience

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Background: The ‘‘elephant trunk’’ (ET) technique traditionally has been performed to treat complex aortic diseases involving the aortic arch and the descending aorta. Despite the fact that, in recent years, the ‘‘frozen elephant trunk’’ (FET) technique has been used increasingly for such pathologies, discussion is still ongoing in the surgical community regarding which of the 2 techniques is better. We compared our results using the classic ET versus the FET technique.

Methods: From August 2001 to March 2013, a total of 277 patients underwent total aortic arch replacement and either ET (group A) or FET (group B) implantation. In group A, 97 patients (59 men; age 59.7 ± 12.7 years; 44.3% with aneurysm; 55.6% with dissection [48.45% acute]) underwent an ET procedure; 21.64% were reoperations. In group B, 180 patients underwent an FET procedure (126 men; age 59.8 ± 13.2 years; 34.4% with aneurysm; 63.3% with dissection [35% acute]); 30% were reoperations.

Results: In group A, in-hospital mortality was 24.7%; postoperative stroke rate was 12.4%. During follow-up, 27.8% underwent a second-stage procedure. In group B, in-hospital mortality was 12.2%; postoperative stroke rate was 13.3%. During follow-up, 27.7% patients underwent further interventions in the downstream aorta.

Conclusions: In selected patients with combined aortic arch and descending aortic aneurysms limited to the proximal descending aorta, the FET approach potentially allows for single-stage therapy, whereas a second-stage operation is inevitable with the classic ET approach. Moreover, owing to the availability of prefabricated, easy-to-use, FET, hybrid prostheses that result in significantly better outcomes in patients who have acute aortic dissection, type A, and if necessary, and provide an ideal ‘‘landing zone’’ for future endovascular completion, the classic ET procedure is ‘‘freezing,’’ in the sense that it is being replaced by the FET approach. (J Thorac Cardiovasc Surg 2015;149:1286-93)

See related commentary on pages 1294-5.

Various approaches have been used to treat the combined pathologies of the aortic arch and the descending aorta (aneurysms and dissection). Borst and colleagues[1] introduced the ‘‘elephant trunk’’ (ET) technique at our center, designed to simplify the second-stage operation of the 2-stage procedure.[2-4] Endovascular stent-graft technology was introduced in 1998 by Dake and colleagues,[5] to treat aortic pathology.[6] A combination of the above 2 techniques resulted in the ‘‘frozen elephant trunk’’ (FET) technique,[7] which therefore represents an evolution of the classic ET procedure. The purpose of the current study was to compare our results from use of the classic ET versus the FET procedure.

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METHODS

Patients

The ET technique was first introduced at our center in March 1982, whereas the first FET implantation was performed in August 2001. To compare the results of the 2 procedures, we decided to include the data for both groups, dating from the first FET implantation (2001). The ethics committee of our institution gave approval for this study.

From August 2001 to March 2014, a total of 277 patients underwent total aortic arch replacement with either ET (group A, n = 97) or FET (group B, n = 180) implantation. Prospectively collected patient records were reviewed. Clinical follow-up ended in March 2014 and was 100% complete. Overall, the characteristics of patients in the 2 groups were comparable. However, group A had significantly more patients with acute aortic dissection, type A (AADA) (n = 47 [48.5%] vs n = 63 [35.0%]; $P = .039$); whereas group B had more patients with chronic aortic dissection, typeA (n = 7 [7.2%] vs n = 51 [28.3%]; $P < .0001$). Group A had a higher percentage of patients with Marfan syndrome (n = 3 [5.4%] vs n = 3 [4.8%]; $P = .003$).

We believe that aortic aneurysms, acute aortic dissections, and chronic aortic dissections are 3 separate disease entities, with different sets of risks. Accordingly, we divided both study cohorts into 3 subgroups. Preoperative demographic patient characteristics are reported in Table 1.

Surgical Technique

Classic ET technique. The early version of the ET technique was performed between 2001 and 2006. In this procedure, the ET part of the aortic graft was inserted per Svensson and colleagues' modification[4] of the original technique.[2] The supra-aortic vessels were reimplanted in the aortic arch prosthesis using the classic ‘‘island’’ technique.

Abbreviations and Acronyms

AADA = acute aortic dissection, type A
ET = elephant trunk
FET = frozen elephant trunk
TEVAR = thoracic endovascular aortic repair

Prefabricated ET technique. The later version of the technique, known as prefabricated ET, has been used since 2007. In this procedure, a prefabricated branched aortic arch graft is used with an ET part (Siena, Vascutek, Ltd, Renfrewshire, Scotland, United Kingdom).[8-10] The arch part of the graft has 4 branches, 1 for arterial perfusion, and 3 for the anastomoses with the supra-aortic branches. Between the ET and the arch parts of the graft is a sewing collar, designed to simplify the distal anastomosis.

Frozen elephant trunk technique. During the early years of this procedure (2001-2007), the first ‘‘prefabricated,’’ custom-made Chavan-Haverich hybrid graft (Curative GmbH, Dresden, Germany) was implanted. We changed to the E-VITA Jotec hybrid graft (JOTEC GmbH, Hechingen, Germany) when it became available. Later, we developed, along with Vascutek (Renfrewshire, Scotland, United Kingdom) the Thoraflex Hybrid multi-branched graft and distal stent.[11]

Technical Evolution of the ET and FET Techniques

We recently published a report of our 30-year experience with the conventional ET technique, as well as of our 10-year experience with the FET technique.[12,13] We identified several parameters that need to be improved, and initiated changes in perioperative management, as follows:

- Reduction of perioperative stroke rate: We use carbon dioxide sufflation in the operative field to reduce the risks of air embolism.
- Myocardial protection: To minimize the myocardial ischemia time, we initiated the ‘‘beating heart’’ aortic arch repair technique.
- Spinal cord protection: To minimize the risks of paraplegia, the lower-body circulatory arrest time is kept to a minimum, and perioperative cerebrospinal fluid drainage is performed in all FET procedures, to keep the spinal pressure below 12 mm Hg. In patients undergoing ET procedures, cerebrospinal fluid drainage is used according to anatomic needs.
- Shortening of the hypothermic circulatory arrest and cardiopulmonary bypass times: We restart the perfusion of the lower part of the body, as well as begin ‘‘rewarming,’’ immediately after the distal aortic arch anastomosis.
- Hemostasis: To improve hemostatic control over every anastomotic site, aortic arch repair has been performed exclusively with branched aortic arch grafts since 2007.
- Recurrent nerve palsy: If technically feasible, we perform the distal aortic anastomosis proximal to the left subclavian artery, to minimize surgical dissection and manipulation of the distal aortic arch.

Current Technique for Total Aortic Arch Surgery Using ET and FET

After a standard median sternotomy, cardiopulmonary bypass is initiated with direct cannulation of the aorta and the right atrium. We prefer direct cannulation of the aorta in all cases, including acute and chronic aortic dissections. The left side of the heart is vented through the right superior pulmonary vein. Continuous carbon dioxide insufflation is used in all cases.

Blood cardioplegia is our preferred method of myocardial protection. Cardioplegia is repeated approximately every 30 minutes during the cardiac part of the procedure. Cerebral protection is achieved by moderate hypothermic circulatory arrest at 25°C, along with bilateral selective antegrade cerebral perfusion. During the time the patient is cooled to a nasopharyngeal temperature of 25°C, the aortic root and/or ascending aortic procedure and other concomitant cardiac procedures are performed.

Subsequently, the left ventricle is de-aired, and the heart is perfused in antegrade fashion via an aortic root cannula inserted proximal to the aortic clamp in the ascending aorta or aortic prosthesis. Both the perfusion pressure and flow are continuously monitored. Myocardial perfusion pressure is kept at 70 to 80 mm Hg, corresponding to a myocardial perfusion flow of ≥150 to 200 ml/minute. The left atrium is thoroughly vented. After this step, the aortic arch is replaced on an empty ‘‘beating heart.’’

After reaching the desired temperature, the systemic circulation is arrested and the aorta opened. With the patient in the Trendelenburg position, catheters (Medtronic DPL, Medtronic, Inc, Minneapolis, Minn) are introduced into the left carotid artery and the innominate artery for selective antegrade cerebral perfusion. The left subclavian artery is clamped or occluded with a Fogarty catheter (Baxter Healthcare Corp, Irvine, Calif), thus avoiding the steal phenomenon, as well as preventing blood from flowing into the operative field. Cerebral perfusion is initiated at a rate of 10 ml/kg/minute. The blood temperature of selective antegrade cerebral perfusion is 22°C to 24°C.

The aorta is transected, either between the left common carotid artery and the left subclavian artery, or distal to the left subclavian artery. The ET or FET is deployed into the proximal descending aorta. With the FET, we routinely use retrograde placement of a guide wire, via femoral access. In addition, we use an endoscope to control the deployment of the ET or FET from inside, after its placement in the descending aorta.

After the distal anastomosis has been completed, the left subclavian artery is anastomosed to the third branch of the arch graft. The perfusion to the lower part of the body and the subclavian artery is restarted via the 4th branch of the graft. ‘‘Rewarming’’ of the patient is initiated.

The proximal end of the graft is anastomosed, either to the native ascending aorta or the ascending aortic graft. In this way, not only the myocardial ischemia time, but also the rewarming time, and consequently the total operation time, is minimized. The 1st and 2nd branch of the Dacron graft are anastomosed to the innominate and left carotid artery, respectively. Once the cardiopulmonary bypass is discontinued, the 4th branch, used for antegrade perfusion, is ligated and resected.

Statistical Analysis

Data were collected and analyzed retrospectively. GraphPad Prism 6.1 for Windows (GraphPad Software Inc, La Jolla, Calif) and SPSS 22.0 (SPSS, Inc, Chicago, Ill) were used to perform data analysis. Continuous variables were given as mean ± SD. Categoric variables were summarized as total number (n) and percentages. The Fisher exact test was used to analyze differences of dichotomous variables. The unpaired *t* test, or as appropriate, the nonparametric Mann-Whitney *U* test were used for group comparisons of continuous variables. The Kaplan-Meier survival estimate was used to analyze survival. Statistical differences in Kaplan-Meier survival were determined with the log-rank test. Two-tailed *P* values < .05 were considered significant. All short- and long-term comparisons were unadjusted.

RESULTS

The detailed intra- and post-operative data are given in Tables 2 and 3. The results from risk factor analysis and multivariate analysis are presented in Tables 4 and 5. Two intraoperative deaths occurred in group A (2.1%). Both of them were patients who had acute dissection. One patient died as a result of myocardial failure; the other died from distal aortic rupture. In addition, 2 intraoperative deaths occurred in group B (1.1%). Both of these patients had acute aortic dissection. One patient could not be weaned