Review Article

Is a four-branched prosthesis advantageous over a straight prosthesis in Frozen elephant trunk surgery?

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Abstract: For years, the elephant trunk (ET) technique has been applied to extended aortic arch pathology facilitating staged downstream open- or endovascular completion. The recent use of a stentgraft as so-called frozen ET enables even single-stage repair, or its use as a scaffold in an acutely or chronically dissected aorta. Hybrid prosthesis have since been introduced, available as either a 4-branch graft or a straight graft for reimplantation of the arch vessels using the classic island technique. Both techniques are known to have technical advantages and disadvantages in specific surgical scenarios. In this paper we will discuss whether a 4-branch graft hybrid prosthesis is advantageous over a straight hybrid prosthesis. Our considerations in terms of mortality, cerebral embolic risk, myocardial ischemia time, cardiopulmonary bypass (CPB) time, hemostasis and exclusion of supra-aortic entries in the case of acute dissection will be shared. The 4-branch graft hybrid prosthesis conceptually facilitates reduced systemic-, cerebral-, and cardiac arrest time. Additionally, atherosclerotic ostial debris, intimal re-entries, and fragile aortic tissue in genetic disease can be excluded by using a branched graft instead of the island technique for reimplantation of the arch vessels. Despite many conceptual technical advantages of the 4-branch graft hybrid prosthesis, literature data do not show significantly better outcomes when compared to the straight graft, to support its routine use in all cases.

Keywords: Arch replacement; frozen elephant trunk (FET); island technique; separate graft technique

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Introduction

Surgical management of aortic arch pathology remains a formidable challenge. Apart from the impact on cardiac, cerebral, and systemic perfusion, aortic pathology is seldomly limited to the arch itself. In most cases, the dilatation continues into the descending thoracic or even thoraco-abdominal aorta. The 'elephant trunk' (ET) technique as originally described by the group of Professor Borst (1) in 1983 greatly facilitates a second-stage descending procedure after replacement of the aortic arch. The basic principle of this technique includes a free floating segment of vascular graft into the descending aorta that is continuous with the arch repair. In a second stage procedure, this ET can be used to crossclamp and create the proximal anastomosis for an open thoraco(-abdominal) aortic repair, avoiding the need to again manipulate the hostile region of the distal aortic arch, including the recurrent laryngeal nerve.

The presence of an ET also enables the use of left heart bypass (LHB) instead of deep hypothermic circulatory arrest (DHCA) for the staged downstream aortic resection when no safe clamping site is available in the situation of a mega-aorta syndrome.

Alternatively, the ET can be used as proximal landing zone for endovascular completion in case of suitable distal aortic anatomy. Since in many patients the ET is created

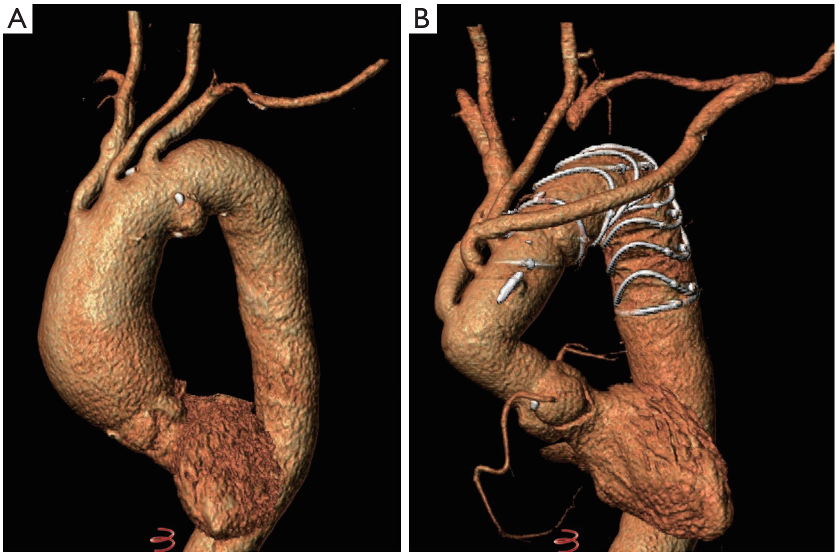

Figure 1 Separate branch technique. (A) Preoperative 3D-reconstructed CT-scan. Ascending aortic aneurysm (62 mm) continuous with the proximal arch, together with an atherosclerotic saccular dilatation distally. (B) Postoperative 3D-reconstructed CT-scan. Supracoronary ascending aorta and total arch repair with 4-branch graft hybrid prosthesis as FET. The left subclavian artery is revascularised using an extra-anatomic transpleural dacron graft. CT, computed tomography; FET, frozen elephant trunk.

provisionally to be used in later dilatation, in only about half of the cases ET surgery is actually followed by a second-stage descending procedure (2). Additionally, the magnitude of the surgical trauma of the first stage and the needed time for recovery for the second stage may result in interval mortality (4%) in those scheduled for two-staged repair of a mega-aorta (3). These observations prompted development of the so-called 'frozen elephant trunk' (FET) procedure; combining a regular vascular arch prosthesis with a distal stentgraft as ET. In case of distal sealing and fixation [like in thoracic endovascular aortic repair (TEVAR)], the FET technique results in a single-stage repair of extended arch pathology through median sternotomy. Later, the FET was also used as scaffold in patients with both acute or chronic aortic dissections to induce remodeling of the downstream dissected aorta. Whether the benefits outweigh the additional risks in acute type-A aortic dissection is still being debated. In selected patients, however, with the proximal intimal entry tear located in the proximal descending aorta or with downstream severe malperfusion, the FET technique may provide a reasonable solution for single-stage repair, although also hybrid, staged repair is a valuable option (4). In case of need for early surgical intervention in type-B aortic dissection (for severe malperfusion or false lumen rupture) due to absence of an adequate proximal landing zone for TEVAR, the FET is a well-suited surgical technique. Similar to TEVAR, positive aortic remodeling of chronic (residual) post-dissection aneurysms have been observed by simply occluding the proximal intimal (re-) entries using the FET technique. Initially hand-made individual devices were used. Since roughly 10 years now, hybrid FET prostheses have been introduced to market and commercialized. In Europe, most of the reported experience includes the Thoraflex Hybrid (Terumo Aortic, Inchinnan, UK) and Evita Open (Jotec GmbH, Hechingen, Germany). Both hybrid prostheses are available as either a 'branched graft', or 'straight graft' for reimplantation of the arch vessels using the classic island technique ('en-bloc'). Both have from a separate branch, used to reinstall antegrade systemic reperfusion by connecting the arterial line of the cardiopulmonary bypass (CPB) circuit. In this paper we will discuss whether a 4-branch graft FET hybrid prosthesis is advantageous over a straight FET hybrid prosthesis by comparison (*Figures 1,2*).

'Branched graft technique' (BGT) versus 'en-bloc technique' (EBT) (island)

Mortality

Although no head-to-head comparison of the BGT and

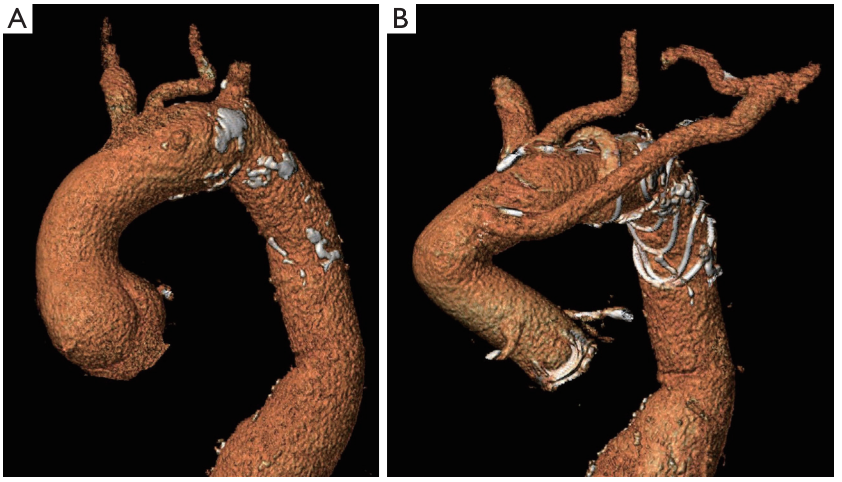

Figure 2 Island technique. (A) Preoperative 3D-reconstructed CT-scan. Aortic root (60 mm) and ascending aorta aneurysm, together with penetrating aortic arch ulcera distally, following open descending thoracic aorta repair. (B) Postoperative 3D-reconstructed CT-scan. Bentall procedure and total arch repair with straight graft hybrid prosthesis as FET. The arch vessels are reimplanted using the en-bloc, island technique. The left subclavian artery is revascularised using an extraanatomic transpleural dacron graft. CT, computed tomography; FET, frozen elephant trunk.

EBT is available in the present FET literature, it seems plausible to assume that there is no difference in the risk of mortality. Two large comparative cohort studies (5,6) of patients undergoing conventional ET procedures with either the BGT or EBT in Europe and Japan showed no differences in hospital mortality.

Cerebral embolic risk

Cerebral embolization is a feared complication of aortic surgery. A recent meta-analysis (7) including 3,154 FET patients reported a substantial risk of 7.6% permanent or transient stroke. The occurrence of peri-operative stroke is multifactorial; it may be caused by factors as embolization of atheroma, clot or air, by malperfusion of certain areas of the brain during antegrade selective cerebral perfusion, or by inadequate hypothermic protection during circulatory arrest. The use of a four-branched hybrid FET graft facilitates replacement of the total arch including the origin of the supra-aortic vessels where atheroma and clot are often present. In this perspective, the use of the BGT may theoretically lower the risk of stroke, although the two available cohort studies comparing the BGT with the EBT in conventional ET surgery do not confirm this quantitively; the Hannover study by Shrestha and colleagues (5) reported a stroke rate of 4.3% in the BGT versus 3.8% in the EBT (no statistical significance); the combined cohort from Ancona, Italy, St. Antonius Hospital Nieuwegein, The Netherlands, Hamamtsu, Japan and Bologna, Italy (6) revealed a stroke rate in conventional ET surgery of 4% in the BGT group versus 2.5% in the EBT (no statistical significance) and a transient neurological damage rate of 5.5% in the BGT group versus 5.2% in the EBT group (no statistical significance).

Myocardial ischemia time

One of the main theoretical advantages of the BGT over the EBT is the possibility to reperfuse the heart directly after completion of the stent implantation and completion of the distal suture line. In contrary to the EBT, the BGT allows the surgeon to reconnect and reperfuse the heart after completion of the distal anastomosis while the supra-aortic vessels are still supplied with antegrade selective cerebral perfusion. In the EBT, cluttering of the operative field by the perfused graft simply makes this impossible and it is necessary to perform the anastomosis of the 'island' of the supra-aortic vessels during a period of circulatory arrest. This inevitably leads to a both a longer circulatory arrest time and myocardial ischemia time, both robust risk factors for perioperative mortality and morbidity.

The observational study by Di Eusanio *et al.* (6) confirmed this prolonged myocardial ischemia time (EBT 130±49 *vs.* BGT 116±39 min, P=0.003), although less pronounced in the Hannover cohort (EBT 147±54 *vs.* BGT 140±54 min, no statistical significance).

CPB time

If the surgical strategy that encompasses reperfusion of the heart before reconnecting the supra-aortic vessels as described above is used, rewarming may begin slowly after completion of implantation of the stent and the distal suture line in the BGT. By rewarming the blood temperature to approximately 28 ℃, the heart may restart beating (as at lower blood temperatures it usually fibrillates) while the moderate hypothermia still protects the brain in the unlikely event of technical problems with the bilateral antegrade selective cerebral perfusion. After anastomosing the left common carotid artery, we usually commence full rewarming and, when following this sequence, the heart is reperfused and the body temperature usually normothermic at time of completion of all anastomosis leading to a shorter CPB time which was quantitively also confirmed by Di Eusanio *et al.* (CPB time in the EBT 214±69 *vs.* BGT 200±57 min, P=0.003).

Ischemia time of the lower body and left subclavian artery territory

As reperfusion of the lower body can be directly commenced after completion of the distal suture line in the BGT, the lower body ischemia time can be limited as much as possible and thereby conceptually limiting the risk of spinal cord ischemia. Although the number of events were too low in both observational studies to confirm the benefit is this strategy, it is biologically plausible that shorter ischemia time might lower the risk of paraplegia. With respect to revascularization of the left subclavian artery several strategical considerations should be made; it may be beneficial to perform a (supraclavicular) carotid-to-subclavian bypass before the FET procedure in order to further decrease circulatory arrest time as this anastomosis is usually difficult and impossible to perform without circulatory arrest due to cluttering of the field when the FET graft is employed and perfused. Another option is to perform an extra-anatomical transpleural bypass of the left subclavian artery from the FET prosthesis as advocated by the group of Essen (8), allowing continuous perfusion of all three supra-aortic vessels (and thus enhancing spinal cord protection) and minimalization of the lower body ischemia time.

Hemostasis

For the surgeon, persisting bleeding at an anastomotic suture lines remains one of the most feared technical complications of arch surgery. In this perspective, the BGT provides easier visualization of the anastomotic lines in case of bleeding; a bleeding from the posterior aspect ‘island’ in the EBT is virtually impossible to correct after weaning from CPB, should it occur. On the other hand, the anastomosis to the separate grafts may be difficult in the setting of friable tissues, especially in acute dissection cases.

Exclusion of reentries in the supra-aortic vessels

It is well described that re-entries are present in the supra-aortic vessels in up to 30% of all acute DeBakey type I dissection patients (9). These tears act as re-entry tears in the aorta, perfusing the false channel and leading to unfavourable aortic remodeling after aortic dissection repair if left untreated. Although our groups do not regularly use the FET technique in the setting of acute DeBakey type I repair because of the risks of spinal cord ischemia and because of the technical complexity with debatable downstream benefits, the exclusion of supra-aortic re-entries by using the BGT is theoretically beneficial for remodeling of the dissected thoraco-abdominal aorta.

Proximalization of the distal anastomosis

One of the technical benefits of the BGT is the possibility to perform the distal anastomosis in zone 2 (i.e., between the left common carotid artery and the left subclavian artery) instead of zone 3 (just distal of the left subclavian artery). This greatly simplifies the surgical complexity of the distal suture line, especially in cases with a relatively ‘narrow’ arch in whom the distal suture line in zone 3 can be demanding. The origin of the left subclavian artery may be then ligated and the left-subclavian artery revascularized to personal preference (e.g., extra-anatomical transpleural as mentioned above, or by means of a left carotid to subclavian bypass in the supraclavicular fossa). Another major advantage of proximalization of the distal anastomosis is the prevention of recurrent laryngeal nerve damage as deep dissection of the arch is unnecessary, a complication with major consequences of the patient that should not be underestimated.

Connective tissue disorders

In the case of connective tissue disorders as Marfan's syndrome or Loeys-Dietz syndrome, we are cautious to apply the FET technique because of concerns of distal stent induced new entry's and the occurrence of type Ib endoleak in these patients who are usually young. Nevertheless, the BGT offers the advantage of excluding all pathological arch tissue including the proximal portion of the supra-aortic vessels and thus decreasing the risk of aneurysmal disease in the future if one may choose to apply the FET in these patients.

Conclusions

In this paper, we discuss several technical considerations on the surgical strategy in FET surgery. The branched graft technique offers many technical advantages as the possibility to reperfuse the lower body and heart early, commence early rewarming, conceptually decrease systemic arrest-, myocardial ischemia-, and CPB times and ease visualization in the case of suture line bleedings. However, given the present literature, no clear benefits in terms of morbidity or mortality is observed, that would recommend its use in all cases.

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Footnote

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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