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Invited Review / Davetli Derleme

The frozen elephant trunk technique in acute DeBakey type I aortic dissection

Akut DeBakey tip I aort diseksiyonunda frozen elephant trunk tekniği

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ABSTRACT

Although advances in the field of cardiovascular surgery have improved outcomes for patients with acute DeBakey type I aortic dissection, postoperative in-hospital mortality and morbidity remain substantial. The frozen elephant trunk technique has become a treatment option for this disease and was developed primarily to extend repair into the proximal descending thoracic aorta during aortic arch repair (because the descending thoracic aorta is largely inaccessible via median sternotomy), thus avoiding, delaying, or facilitating subsequent repair of residual native aorta. In this review, we discuss the evidence for and future development of frozen elephant trunk reconstruction for acute DeBakey type I aortic dissection.

Keywords: Acute type I aortic dissection, aortic arch, descending thoracic aorta, frozen elephant trunk, hybrid operation.

ÖZ

Kardiyovasküler cerrahi alanındaki gelişmeler akut DeBakey tip I aort diseksiyonlu hastaların sonuçlarında düzelme sağlamakla birlikte, ameliyat sonrası hastane mortalitesi ve morbiditesi önemini korumaktadır. Frozen elephant trunk tekniği, bu hastalık için bir tedavi seçeneği olup, arkus aort tamiri sırasında proksimal inen torasik aorta uzanacak şekilde tamiri gerçekleştirmek (genellikle median sternotomi ile inen torasik aorta ulaşılamadığı için) ve müteakip rezidüel nativ aort tamirini önlemek, geciktirmek veya kolaylaştırmak için geliştirilmiştir. Bu derlemede, akut DeBakey tip I aort diseksiyonunda frozen elephant trunk rekonstrüksiyonunun kanıtları ve ileriye yönelik gelişmeleri tartışıldı.

Anahtar sözcükler: Akut tip I aort diseksiyonu, aortik ark, inen torasik aort, frozen elephant trunk, hibrid ameliyat.

Despite innovations in cardiovascular surgery, acute dissection of the ascending aorta (DeBakey types I and II or Stanford type A aortic dissection) remains a challenging disease that can have a catastrophic impact on a patient's life. Being the most extensive form of acute proximal aortic dissection, type I aortic dissection extends from the ascending aorta through the transverse aortic arch and into the descending thoracic and thoracoabdominal aorta (Figure 1). The high rates of morbidity and mortality associated with this disease could be the result of either aortic rupture, including rupture into the pericardium, or extension of dissection into the aortic valve or branches such as coronary arteries, supra-aortic trunks, visceral arteries, or extremities.[1,2]

Once acute type I aortic dissection is diagnosed, emergency surgery is imperative. The primary objective during surgical treatment of acute type I aortic dissection is to keep the patient alive; a secondary objective is to reduce the need for subsequent procedures in the residual native aorta. The armamentarium of aortic surgeons includes a wide spectrum of methods, ranging from conventional open surgical procedures to minimally invasive endovascular and hybrid procedures.

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The most common treatment is ascending aorta replacement, with or without hemiarch replacement, leaving portions of the aortic arch and the distal aorta untouched; as a result, the untreated, residually dissected arch, descending thoracic aorta (DTA), and thoracoabdominal aorta are prone to late aortic dilatation. Dilation in the residually dissected distal aorta, especially the isthmus segment, is most often due to dilatation of the false lumen and the elevated hemodynamic stress caused by the convexity of the unstable dissected aortic wall. Indeed, after the traditional treatment of aortic dissection by either hemiarch or total arch replacement, 90% of patients have a patent false lumen.[3,4] Therefore, definitive aortic repair of extensive aortic dissection usually requires more than one surgical or endovascular intervention, depending on the type of disease, anatomy, comorbidities, and surgeon experience.

Here, we analyze the pros and cons of using the frozen elephant trunk (FET) technique to treat acute type I aortic dissection, and we compare this approach with the conventional elephant trunk (cET) technique in clinical practice.

CONVENTIONAL ELEPHANT TRUNK PROCEDURE

The cET procedure, first described in 1983 by Hanover's Borst et al.,[5] is a staged procedure. Briefly, in the first session, median sternotomy and hypothermic circulatory arrest are used to replace varying portions of the ascending aorta along with the entire transverse aortic arch. A free-floating extension of the aortic graft (the "trunk") is invaginated and extended into the proximal DTA to be used in the next session. In the second session, via a left lateral thoracotomy or thoracoabdominal incision, the trunk is retrieved and extended; the trunk eases repair by providing a proximal aortic clamping site that is free of adhesions and facilitates a secure graft-to-graft anastomosis as the DTA or thoracoabdominal aorta is replaced. Depending on the anatomic extent of the aortic disease and patient comorbidities, the second stage can be performed by endovascular stent-graft placement, eliminating the need for a thoracotomy. Some authors suggest that the length of the ET should not exceed 10 cm because a longer trunk is more likely to cause complications

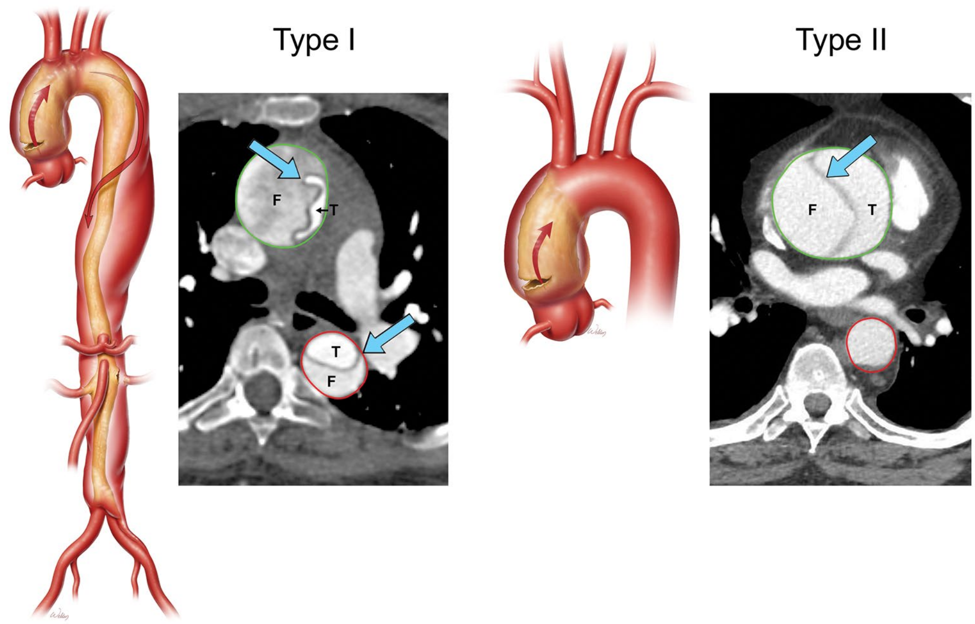

Figure 1. Illustrated scheme showing acute Stanford type A aortic dissection. The dividing membrane between the true lumen (T) and the false lumen (F) is indicated by a blue arrow. Left: DeBakey type I aortic dissection typically extends throughout the entire aorta. Within the proximal aorta (green circle), the false lumen has greatly compressed the true lumen. The dissection continues into the distal aorta (red circle); here, the true and false lumens are roughly equal in size. Right: Limited DeBakey type II aortic dissection. Within the proximal aorta (green circle), the true lumen and false lumen are visible; however, dissection does not extend into the distal aorta (red circle). The DeBakey classification is useful when discussing extensive aortic repair. Used with permission of Baylor College of Medicine.

due to kinking and graft occlusion and to increase the risk of paraplegia due to thrombosis around the graft.[6-8]

Traditionally, the cET repair has been performed in patients with extensive aneurysm or chronic aortic dissection, but a few centers have performed the first stage of the cET repair in patients with acute aortic dissection.[9-11] However, despite reports of good outcomes for the first stage of this procedure in patients with acute dissection, the cET does not address residual patency of the false lumen of the distal aorta and is not proposed as a method to reduce the risk of subsequent distal aortic surgery.[11] In addition, regardless of the aortic disease being treated, in the interval between the two operations, there is a risk of fatal rupture in the untreated segment of the aorta. The advantages of the second-stage cET repair include less dissection and surgical preparation of the distal segment of the arch than standard distal aortic repair entails, and avoiding the need to clamp the left subclavian artery proximally, which may decrease the risk of stroke.

THE FROZEN ELEPHANT TRUNK PROCEDURE

In 1996, Kato et al.[12] proposed a modification of the cET in which a covered endovascular stent-graft is deployed into the DTA during open repair of the aortic arch, thereby distally extending repair and possibly delaying further aortic repair or reducing the risk that it will be needed subsequently. These investigators performed 10 such repairs in patients with aneurysm and chronic aortic dissection. This innovative approach quickly evolved, and in 2003, the Hanover group developed a customized version of the procedure and renamed it the "frozen elephant trunk" procedure.[13] The FET technique has been used to treat both aneurysm and dissection, and several modifications of the technique have been reported.[14-16] The rationale for its use in treating acute aortic dissection lies in the potential for extensive remodeling of the covered portion of the DTA, which may result from radial pressure exerted by placing the stent-graft within the dissection's true lumen, and thus, obliterating a portion of the false lumen. Additionally,

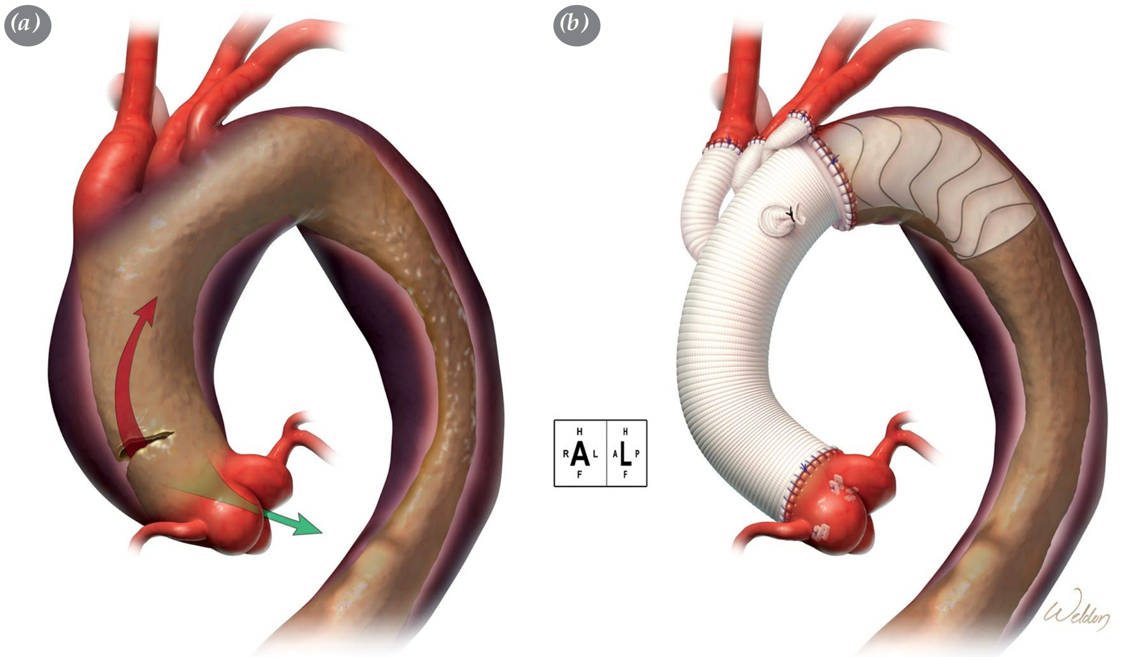

Figure 2. (a) Illustration depicting an acute DeBakey type I aortic dissection with a prominent entry tear above the sinotubular junction. Here, acute aortic valve regurgitation (green arrow) is present after dissection has compromised its integrity. **(b)** A branched hybrid device is used to completely replace the aortic arch and ascending aorta and extend repair into the proximal portion of the descending thoracic aorta as part of a frozen elephant trunk (FET) repair. The endovascular portion of the FET device is placed within the true lumen, resulting in its expansion. The brachiocephalic arteries have been debranched, and the aortic valve has been resuspended to correct aortic regurgitation. Used with permission of Baylor College of Medicine.

the stent-graft stabilizes the dissecting membrane and facilitates true lumen expansion downstream, beyond the portion of the aorta immediately covered by the stent-graft. It is important to choose a prosthesis of appropriate size. Failure to do so could lead to unsuitable oversizing or insufficient sealing of the stent-graft. At our center, FET and related approaches are typically reserved for patients with a primary tear located in the proximal DTA, those with distal malperfusion, and those with a compressed true lumen in the proximal DTA.

Before the procedure, a computed tomography angiogram should be performed to measure the diameter of the true and false lumens at the DTA and to locate the primary tear and any re-entry tears. Basically, FET is a single-stage hybrid procedure consisting of an open antegrade stent-graft repair of the proximal DTA and conventional open surgical replacement of the total arch and ascending aorta (Figure 2). In the beginning, this procedure was performed with separate stent-grafts and aortic Dacron grafts. Nowadays, some centers without access to FET devices still use this approach to repair as an off-label use of aortic stent-grafts to facilitate extended distal aortic repair of acute type I aortic dissection. However, one-piece hybrid FET devices have been widely used in Europe and Asia for over a decade; one of these hybrid FET devices recently received breakthrough device designation in the United States.

Regarding standard FET repair, the most commonly used hybrid prostheses are the Thoraflex hybrid (Terumo Aortic, Sunrise, FL, USA) and the E-vita Open (JOTEC GmbH, Hechingen, Germany).[17-19] The stented portion of these prostheses is available in diverse diameters and differing lengths depending on the manufacturer. One commercially available hybrid prosthesis has four branches at its proximal portion to facilitate reimplantation of the three supra-aortic vessels and more rapid reperfusion of the lower body via a single side branch once the distal anastomosis is completed.

Like all aortic arch repairs, the FET procedure is performed via median sternotomy under hypothermic circulatory arrest; antegrade cerebral perfusion is used to protect the brain. Briefly, once the patient is cooled to a target temperature of 24°C, the initial steps of FET with a commercially available, one-piece hybrid prosthesis include transecting the aortic arch, reinforcing the aortic wall and obliterating the false lumen with Teflon felt, advancing the hybrid system over a guidewire into the true lumen of the DTA, deploying the stent-graft, and suturing the vascular collar of hybrid graft to the previously prepared native distal aorta proximal or distal to the origin of the left subclavian artery. After the collar is secured, the side-branch of the device perfuses the distal aorta. Rewarming the patient begins. The final steps are reconstructing the arch either using an island reattachment strategy or individually reimplanting the supra-aortic vessels into the branched graft, and completing the proximal anastomosis to the proximal supracoronary ascending aorta, addressing the aortic valve or root as needed. Several intraoperative imaging techniques can be used to make stent-graft deployment more accurate, including transesophageal echocardiography, angioscopy, and intravascular ultrasonography.[16,20]

At our aortic center, unless a total arch repair is needed to address arch dilatation, our typical approach to extended repair of acute type I aortic dissection is aggressive hemiarch replacement and antegrade

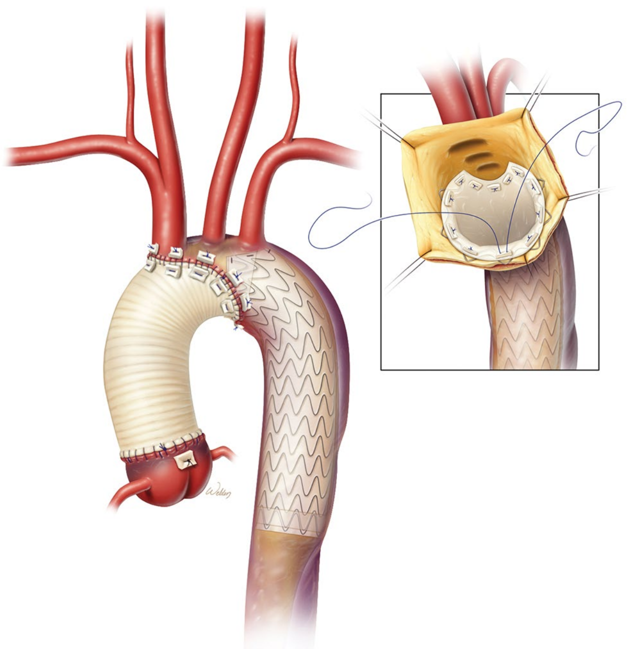

Figure 3. Illustration of an approach combining antegrade thoracic endovascular aortic repair (TEVAR) with limited resection of the aortic arch (ie, hemiarch replacement) in acute DeBakey type I aortic dissection with distal malperfusion. This approach mimics the frozen elephant trunk but only partly replaces the aortic arch. To reduce the risk of distal device migration, the stent-graft has been circumferentially reinforced with pledgeted sutures and incorporated into the distal anastomosis. The aortic valve has been resuspended and reinforced with pledgeted sutures. Inset: To permit blood flow into the left subclavian artery, a small notch has been cut into this stent-graft. Used with permission of Baylor College of Medicine.

stent-graft delivery under direct vision in a single-stage procedure.[15,21] The proximal portion of the stent-graft (Conformable TAG device; W. L. Gore & Associates, Newark, Delaware, USA) is notched to better incorporate the origins of the left subclavian artery and, at that artery's level, facilitate integration of the distal suture line (Figure 3). Then, the stent-graft is sutured circumferentially to reduce the likelihood of distal migration and incorporated into the distal anastomosis of the hemiarch repair; the stent-graft, graft, and residual native aorta surrounding the base of the left subclavian, innominate, and left common carotid arteries are joined with running polypropylene sutures. Pledgeted sutures are used to reinforce the distal suture line. Repair is completed by performing the proximal anastomosis with or without aortic valve or root repair; commonly, in patients with acute aortic dissection, the aortic valve is resuspended unless patient-specific aortopathy necessitates aortic root replacement.

Another example of this approach relies on antegrade insertion of the stent-graft more proximally in the aortic arch by covering the anatomic location of the left subclavian artery with the stent-graft, and followed by either bypass of the artery or the insertion of an endovascular branch into the left subclavian artery to restore perfusion. Notably, the remaining brachiocephalic arteries are left intact, and repair is completed by a single proximal anastomosis.[22]

Also, it is helpful to select a distal anastomosis location more proximal to the anatomic origins of the left subclavian artery to avoid a deep suture line and reduce the risk of bleeding. Theoretically, a more proximal suture line also reduces the likelihood of postoperative spinal cord deficit. Additionally, the length of stent-graft may be important for maintaining spinal cord perfusion.[23] The approximately 10-cm stent-graft portion of the FET is preferred to the 15-cm version, to minimize the risk of postoperative paraplegia.

USE OF ELEPHANT TRUNK PROCEDURES IN ACUTE TYPE I AORTIC DISSECTION

Despite improvements in cardiovascular surgery, surgical mortality is still high, and acute type I aortic dissection continues to represent a great challenge for surgeons. Therefore, a more conservative, tear-oriented approach aimed at performing a more effective and shorter procedure with less morbidity and mortality has generally been adopted. At most aortic centers, standard repair of acute type I aortic dissection avoids total arch replacement and replaces only a portion of the aortic arch (i.e, the lesser curvature of the arch or hemiarch). Basically, cET and FET are similar in terms of the scope of repair of the ascending aorta and the aortic arch: Both approaches completely replace the entire transverse aortic arch and replace a variable portion of the ascending aorta. Both repairs are more involved than our standard approach of limited hemiarch replacement. The major difference between the two techniques is how the dissection involving the DTA is managed. In FET, dissected proximal DTA is treated with a stent-graft in the same operation as ascending aorta and the aortic arch repair. Conversely, at the end of the first stage of cET, the dissected proximal DTA is left unrepaired. In both repairs, a large portion of the thoracoabdominal aorta is left unrepaired, but it is thought that there may be some difference in the remodeling of the residual dissected native aorta, with the FET approach resulting in widespread expansion of the true lumen.

Early mortality

Data from some of the largest studies of patients with ATAAD who underwent FET repair suggest that operative mortality ranges from 3 to 18%.[18,24-29] In a meta-analysis of 15 studies of FET repair in 1,279 patients with acute type I aortic dissection, Takagi et al.[30] reported early mortality of 9.2%. More recently, Inoue et al.[31] compared cET to FET in patients with acute dissection and found similar rates of early mortality. On the other hand, some groups have reported significantly better survival in patients with acute aortic dissection who underwent an FET versus cET. The Hannover group[32] reported that the in-hospital mortality rates in cET and FET patients were 40.4% and 15.9%; furthermore, in multivariate analysis using a stepwise regression model, FET was independently associated with survival. In our series of 178 patients who underwent repair of acute type I aortic dissection between 2005 and 2016, the patients who underwent antegrade thoracic endovascular aortic repair (TEVAR) had better operative mortality than propensity-matched patients who underwent standard hemiarch repair.[21]

Complications

The main neurological complications of FET are stroke and spinal cord deficit (SCD; i.e., postoperative paraplegia or paraparesis). Jakob et al.,[18] who collected data on acute type I aortic dissection patients treated with the E-vita Open hybrid graft, showed 7% and 5% rates of postoperative stroke and SCD, respectively. Similar results were reported by Shrestha et al.[19,33] in 100 acute type I aortic dissection patients treated with the Thoraflex hybrid prosthesis. According to a review of published series of FETs performed to treat acute dissection, postoperative SCD occurs in 4.3% of patients (range, 0%-13.8%) and stroke in 4.8% (range, 0%-12.0%).[28] Spinal cord deficit after traditional total aortic arch replacement (including that as part of the first stage of a cET) is an uncommon event. Conversely, SCD has been described as the Achilles heel of the FET technique. Thus, the FET procedure incurs all the risks typically associated with total arch replacement, as well as the novel risk of SCD.

The risk of SCD is the main concern with placing a stent-graft in the DTA. This risk is principally due to the coverage of the intercostal arteries without revascularization. In their meta-analysis, Takagi et al.[30] reported an SCD rate of 3.5%. In Preventza et al.'s[23] recent meta-analysis of 35 studies of neurological complications in FET cases, 12 studies included repairs of acute type I aortic dissection, performed in 1,300 patients. These patients had a significantly lower incidence of postoperative SCD (2.4%; 95% CI, 1.3-4.2) than patients with chronic type I aortic dissection or aneurysm (5.2%; 95% CI, 3.1-8.5) ($p=0.05$). However, the authors note that the higher rate of mortality and stroke in patients with acute type I aortic dissection may have masked the rates of SCD in this group, whose preoperative conditions can include malperfusion, instability, and poor preoperative neurologic status. Importantly, a landing zone at T8 or beyond or a stent-graft length of 15 cm or more was a significant predictor of SCD.[23] In our series of 178 patients who underwent repair for acute type I aortic dissection, persistent paraplegia/paraparesis rates were comparable in antegrade TEVAR and standard hemiarch repair groups (1.6% vs 0.9%).[21] Evidence regarding the magnitude of SCD after FET is still inconclusive. Therefore, caution is needed to avoid extensive coverage of the DTA during primary repair.

Remodeling of dissected aorta

Remodeling of the residually dissected aorta is commonly thought of in terms of reducing the diameter of the false lumen, as well as increasing thrombosis within the false lumen. Remodeling is hindered by ongoing perfusion of the false lumen; this is generally a result of retrograde perfusion from unrepaired sections of the aorta or from multiple entry tears within an extensive dissection. Studies on survivors of acute type I aortic dissection indicate that an initial aortic diameter >35 mm, a false lumen diameter ≥22 mm, and a large (>10 mm) proximal intimal tear are a risk factors for false lumen patency after traditional limited surgery (i.e, hemiarch approaches) for acute type I dissection.[34,35] Although there are few studies on survivors of cET repair for aortic dissection, findings are mixed regarding whether any substantial remodeling of the distal aorta occurs.[9-11]

Compared with the cET procedure, the FET technique as applied to repairs of acute type I aortic dissection aims to promote true lumen expansion through the radial pressure of the stent-graft placed within the true lumen, thereby decreasing the diameter of the false lumen and, eventually, aiding false lumen thrombosis. Several studies in FET patients show a 90% rate of false lumen thrombosis at the level of the stent-graft; this rate gradually reduces over the length of the uncovered sections, falling to 20% at the celiac axis.[17,36,37] Our mid-term results[21] in patients with acute Type I dissection (mean follow-up duration, 4.6±3.6 years) showed that patients more often had remodeling of the DTA after antegrade TEVAR than after standard hemiarch repair ($p=0.002$). In another study, Inoue et al.[31] reported that postoperative false lumen patency at the level of the left lower pulmonary vein was observed in 77% of cET patients but in less than 30% of FET patients; for the FET patients, this finding reflects a substantial drop from a preoperative patency rate of 73%. However, further downstream, at the level of the celiac axis (within the thoracoabdominal aorta), there was little evidence of a change in patency rates. In their meta-analysis, Takagi et al.[30] reported a false lumen thrombosis rate of 97% at the level of the stent-graft.

Because endovascular repair is generally considered inadvisable in patients with Marfan syndrome, the use of FET approaches in such patients remains limited. However, some institutions favor the use of FET approaches even in patients with Marfan syndrome. Chen et al.[38] reported on 172 patients with Marfan syndrome and acute or chronic type I aortic dissection who were followed up for an average of 6 years after repair. For the 94 patients with acute dissection, an acceptable early mortality rate of 7% was achieved, along with rates of 3% and 2% for stroke and SCD, respectively. The aortic growth rate (mm/y) was greatly reduced in the segment of the aorta covered by the FET device but was as great as 4.5 mm/y in the uncovered aortic segment near the diaphragm. Over time, 30% of patients in the acute phase had distal aortic dilation, and 15% underwent distal reintervention, mostly open thoracoabdominal aortic replacement.

Reintervention after FET

Although the FET technique has potential advantages over the cET procedure, FET repairs only a small portion of the residually dissected distal aorta. The need for postoperative imaging surveillance to periodically assess the distal aorta remains, and some patients will probably need subsequent aortic reintervention. A meta-analysis by Takagi et al.[30] of 15 studies of the FET approach in patients with acute aortic dissection determined an overall reintervention rate of 10%. Similarly, a long-term study of 120 such patients determined that freedom from reintervention was 90% at 10 years and 74% at 15 years.[24] In an analysis of more than 300 patients who underwent FET to treat aneurysm, acute aortic dissection, or chronic aortic dissection, Tsagakis and Jakob found that patients with acute aortic dissection had substantially less reintervention than those with chronic dissection or aneurysm; at 8 years, freedom from downstream reintervention was 85% versus 57% and 65%, respectively.[20] The study by Leone et al.,[25] supports the finding that patients who undergo FET repair of acute dissection tend to have lower rates of reintervention. When distal aortic reintervention is necessary, it can be performed in an open or endovascular fashion. Typical reintervention procedures include additional stent-graft placement in the aorta and conventional open replacement with the aortic graft directly anastomosed to the stent-graft portion of the FET prosthesis.

Conclusion

The frozen elephant trunk approach is a valuable addition to the surgeon's toolkit for treating acute type I aortic dissection. Unlike conventional total arch replacement, this extended repair promotes remodeling of the proximal segment of the descending thoracic aorta by extending a stent-graft into the true lumen. Before widespread adoption of the frozen elephant trunk procedure can be justified, further investigations will be needed to identify the appropriate patients with the appropriate anatomic criteria to better understand the potentially enhanced risk of spinal cord ischemia.

Declaration of conflicting interests

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