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The Fate of Conventional Elephant Trunk in the Frozen Elephant Trunk Era

Alexander Geragotellis[1] Matti Jubouri[2] Mohammed Al-Tawil, MD[3]
Idhrees Mohammed, MS, MCh, FAIS[4] Mohamad Bashir, MD, PhD, MRCS[4,5,6] Saeid Hosseini, MD, FETCS[6]

[1] Faculty of Health Sciences, University of Cape Town, Observatory, South Africa
[2] Hull York Medical School, University of York, York
[3] Faculty of Medicine, Al-Quds University, Jerusalem, Palestine
[4] Institute of Cardiac and Aortic Disorders (ICAD), SRM Institutes for Medical Science (SIMS Hospital), Chennai, Tamil Nadu, India
[5] Department of Vascular & Endovascular Surgery, Velindre University NHS Trust, Health Education and Improvement Wales (HEIW), Cardiff, United Kingdom
[6] Heart Valve Disease Research Centre, Rajaie Cardiovascular Medical and Research Centre, Iran University of Medical Sciences, Tehran, Iran

Address for correspondence Mohamad Bashir, MD, PhD, MRCS, Department of Vascular and Endovascular Surgery, Velindre University NHS Trust, Health Education & Improvement Wales, Cardiff CF15 7QZ, United Kingdom (e-mail: drmbashir@mail.com).

Aorta (Stamford)

Abstract

Conventional elephant trunk (cET) and frozen elephant trunk (FET) are two distinct approaches to the surgical treatment of thoracic aortic aneurysms and dissections. With the advent and growing uptake of endovascular technologies, FET is becoming increasingly popular for its potential to be performed as a single-stage operation with better aortic remodeling and less risk of graft kinking than the traditional two-stage cET procedure. However, FET has been associated with a higher risk of spinal cord ischemia and its use in patients with connective tissue disorder remains controversial. The current review aimed to reflect on recent evidence surrounding the application of cET and FET to different types of aortic pathology in both acute and elective settings. Another scope of this review was to compare the characteristics of the currently available FET commercial devices on the global market. Our findings highlight that when the pathology is confined to the proximal descending aorta, such as in Dsine, intervention is often single-staged and false lumen (FL) thrombosis is achieved with good effect. FET remains limited by spinal cord injury and applicability in patients with connective tissue disorder, although some groups have started to circumvent associated complications, likely due to growing surgical expertise. Many other aortic diseases do require second-stage intervention, and even in these cases, there appears to be lower in-hospital mortality when using FET over cET. This is possibly due to the higher rate of endovascular completion facilitated by the completed landing zones created during FET. FET is trending toward becoming the universal treatment modality for extending repair to the descending aorta

Keywords
- conventional elephant trunk
- frozen elephant trunk
- thoracic aorta
- aortic dissection
- aortic aneurysm

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Conventional elephant trunk (cET) and frozen elephant trunk (FET) are two distinct approaches to the surgical treatment of thoracic aortic aneurysms and dissections. The introduction of cET to the aortic surgery arena in 1983 by Borst[1,2] was the beginning of an era for the open two-stage repair of disease affecting both the aortic arch and the more distal aorta. Major procedural concerns related to the cET include the cumulative risk of two major surgical interventions, the interval mortality between the two stages, and losing a large percentage of patients in the second operation.[3–5]

The use of the FET technique was initially experimental, before it was formally introduced in 1996, offering a more contemporary hybrid method, typically performed in a single stage via combining open and endovascular repair.[6,7] However, many aortic cases still require more than one intervention, as each case differs according to center experience and the demographic, anatomical, and disease characteristics of the patients.[3,8] It is useful that polyester-based FET grafts are generally clampable with good recoil and are therefore amendable to repeat intervention.

FET has experienced progressive international uptake over the last decade, bringing to question the future of cET in the contemporary management of aortic pathology. FET unites principles of cET and endovascular repair in an attempt to achieve single-stage repair of extensive aortic arch disease, thus mitigating the risk of interstage mortality, facilitating distal endovascular repair, and often eliminating the morbidity associated with the open distal aortic repair.[4,9–11] Reintervention is common but is associated with acceptable morbidity and mortality.[12–15]

One major commercial FET product is the Thoraflex Hybrid (Vascutek, Terumo Aortic, Inchinnan, Scotland).[16–18] Thoraflex Hybrid is considered by some experts to be more advanced than other commercial FET devices, as it incorporates a quadrifurcated proximal vascular portion to facilitate reimplantation of the epiaortic vessels.[17] Most of the FET operations in the United States used to employ a combination of a Dacron graft and an antegrade deployed conventional thoracic endovascular aortic repair (TEVAR) stent grafts. Recently, the FET-specific Thoraflex hybrid device was approved for commercial use in the United States.

One scope of this review is to compare the technicalities of contemporary FET devices. Another aim is to explore FET with regard to its characteristics, technical details, and outcomes of its application to complex aortic pathologies involving the ascending aorta, the aortic arch, and the descending aorta.

Elephant Trunks Compared: Frozen Elephant Trunk Versus Conventional Elephant Trunk

FET and cET (evaluated in ►**Table 1**–[19–22]) are similar in terms of the scope of repair of the ascending aorta and the aortic arch. Both approaches replace the transverse aortic arch and replace a variable portion of the ascending aorta. FET avoids damage to vital anatomical structures (e.g., pulmonary artery, esophagus, vagus and recurrent laryngeal nerves, and thoracic duct) by eliminating open second-stage intervention. Traditional distal anastomosis of FET was performed at aortic zone 3. In recent years, preference has gradually shifted toward zone 2, and even reaching zone 0, as they were associated with better surgical accessibility and shorter bypass, cerebral perfusion, and cardioplegia time. Therefore, the nomenclature of total replacement of the transverse arch can be inaccurate, especially when performing an FET with a more proximal zone anastomosis.[23]

A principal difference between the two elephant trunk techniques regards how the dissection involving the distal thoracic aorta (DTA) is managed. In the first stage of cET, the focus is on excising the entry tear and repairing the ascending and the transverse aortic arch. This is followed by a second-stage endovascular stenting of the dissected DTA. In contrast, the FET allows for the dissected proximal DTA is to be treated with a stent graft in the same operation as the ascending aorta and aortic arch repair. ►**Fig. 1** shows extensive thoracoabdominal aortic aneurysm angio-computed tomography (CT) 3D-reconstruction along with cET treatment stages[24]

FET results in widespread expansion of the true lumen and coverage of proximal descending aortic entry tears via the radial forces exerted by the stent graft, thus increasing true lumen flow and decreasing FL diameter. However, if patients are not carefully selected, or if the disease progresses into the downstream aorta, which can be expected due to the mixed nature of many aortic disease cases, a second-stage procedure may still be imperative when using FET.[3] Prognosis is better when using a guidewire in the procedure and when applied to patients under 60 years of age.[25] ►**Fig. 2**–[26] shows pre- and postoperative CT scans for different indications for FET.

Table 1 Evaluation of conventional elephant trunk (cET) and frozen elephant trunk (FET) procedures, which both facilitate thoracoabdominal intervention

	Advantages	Disadvantages
cET	Simplifies distal aortic arch anastomosis, reducing risk of ischemic visceral complications	2 stage procedure—high cumulative surgical risk[3–5]
		Interval mortality[19,69–71]
	Lower rates of spinal cord injury[17–20]	May fail to address residual FL patency[43,44,50]
		Graft kinking
FET	Mostly 1 stage procedure	Spinal cord injury[30,92]
	Reduces risk of repeat aortic surgery via better FL thrombosis	
	Limited graft kinking	

Fig. 1 (**A**) Extensive thoracoabdominal aortic aneurysm angio-CT 3D-reconstruction. (**B**) Surgical result after the first cET procedure and (**C**) after the second hybrid procedure (open visceral rerouting + stent graft coverage of the thoracic aorta). Reproduced from Di Bartolomeo et al.[24] Copyright permission to reuse had been obtained from Oxford Academic Group.

Types of Frozen Elephant Trunk Devices

The five most popular commercially available FET grafts are summarized in ►**Table 2**.[27] In Europe, there are currently two commercial FET grafts with the Conformité Européenne mark. These are the Thoraflex Hybrid and E-Vita Open (JOTEC GmbH, Hechingen, Germany). The E-Vita Open was the first commercially available hybrid prosthesis, made available in 2008. The proximal part is a vascular prosthesis and the distal part is a self-expandable Z-shaped nitinol-wired stent graft. In 2020, E-Vita NEO became available, which is designed to offer greater options for epiaortic revascularization. However, early evidence suggests that postanastomotic oozing from the polyester portion of this proximal graft remains a concern.[28] In contrast, Thoraflex Hybrid, available since 2012, has a quadrifurcated proximal vascular portion with differently shaped distal self-expandable nitinol stents. The quadrifurcated proximal portion facilitates individual arch vessel reimplantation. Also, once the distal anastomosis is completed, it facilitates reperfusion of the lower body through the fourth branch. The branched nature of Thoraflex Hybrid facilitates arch vessel reconstruction, whereas Thoraflex Hybrid Ante-Flo facilitates island technique reconstruction (Carrel patch). Both E-Vita Open and Thoraflex Hybrid have a sewing collar to facilitate distal anastomosis. These grafts are available in variable lengths (120–130 or 175–180 mm) for the Evita Open ; 100 or 150 mm for the Thoraflex Hybrid) and diameters (22–40 mm for the E-Vita Open; 24–40 mm for the Thoraflex Hybrid).

Outside of Europe, there is the Frozenix J Graft Open Stent graft (Japan Lifeline Co. Ltd., Tokyo, Japan) and Cronus Open (Microport, China). Frozenix J Graft Open Stent graft was introduced in 2014. There is a proximal unstented graft and distal-stented part made of a polyester tube that uses a unique double-layered oval-shaped nitinol stent. The oval-shaped stented portion is molded to match the aortic curvature upon insertion of the device. Postdeployment and completion of the distal anastomosis, the arch vessels are reconstructed with a separate branched graft in an end-to-end fashion. Three lengths are available (60, 90, and 120 mm) and the diameter of the stent graft ranges from 17 to 39 mm. The arch vessels are sewn with a separate branched graft during the distal anastomosis on the aortic arch.

Another graft in the Asian market, with wide uptake in South America, is the Cronus Hybrid Graft (MicroPort, Shanghai, China). Instead of having an unstented proximal portion, there is a ± 1 cm sewing cuff which can be anastomosed to another commercially available arch graft. The distal stented portion is Z-shaped conichrome, which is a cobalt–chromium alloy. Proximal and distal diameters range between 21 and 32 mm. Device delivery is easy and is achieved using a pull wire and grip handle. The length of the device (150–200 mm) depends on the length of the stent graft, which can range between 40 and 150 mm. ►**Fig. 3** shows examples of different commercially available FET devices.[29]

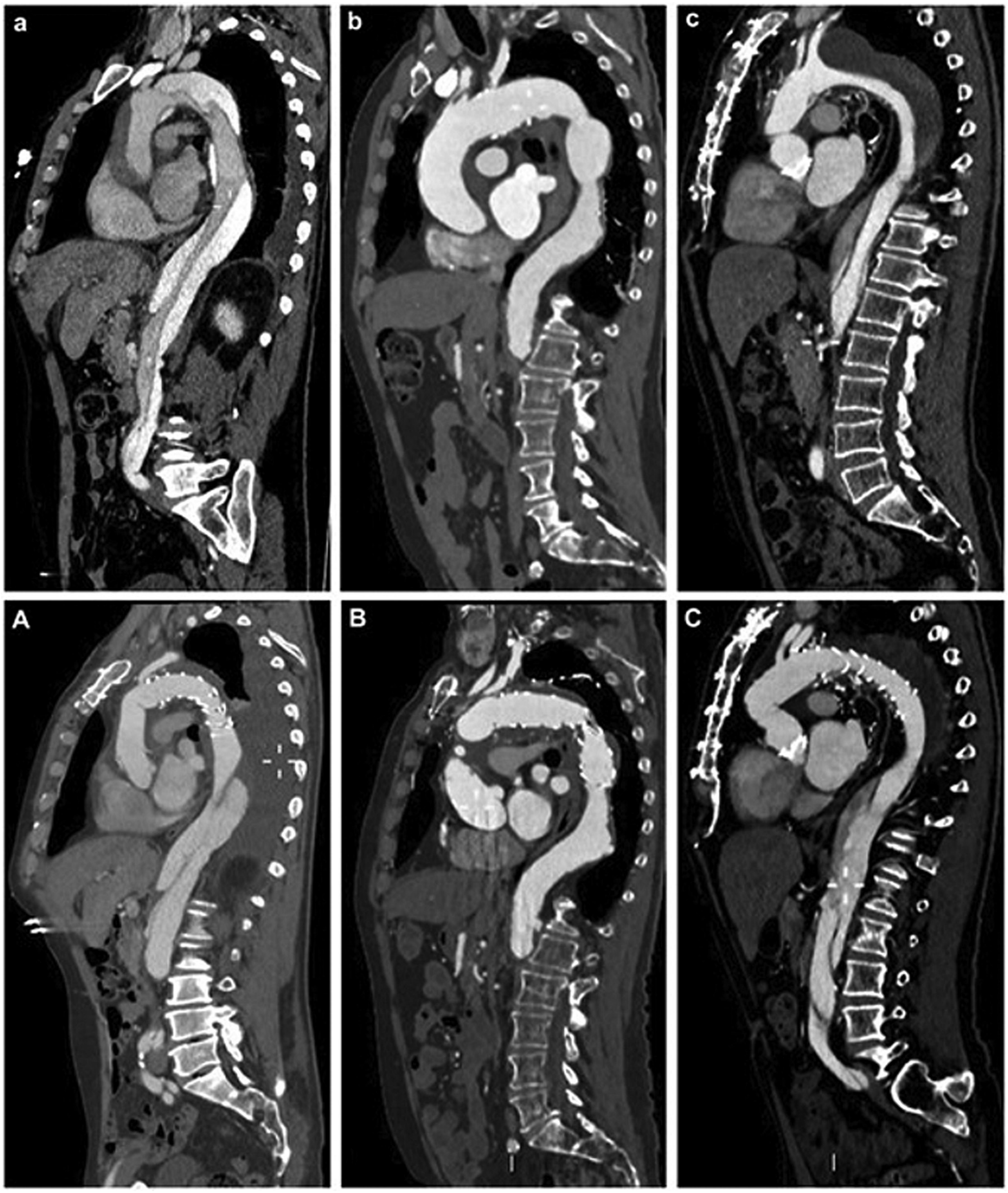

Fig. 2 Indications for the FET technique and preoperative and postoperative CT scans: (**a** and (**A**)) acute Type A aortic dissection; (**b** and (**B**)) degenerative aneurysm; and (c and **C**) residual Type A dissection with aortic root aneurysm. Reproduced from Leone et al[26]. Copyright permission to reuse had been obtained from Oxford Academic Group.

Frozen Elephant Trunk: "Freezing" Mortality and Stroke

FET has comparatively lower mortality than cET. A 2020 meta-analysis (35 studies, 3,145 patients) by Preventza et al,[30] which exclusively explored total arch FET procedures, found 8.8% (95% confidence interval [CI]: 7.0–10.9) pooled operative mortality. However, this pooled result is inflated due to the inclusion of both emergencies (53.2%) and elective cases. Upon subgroup analysis of emergency acute Type A aortic dissection (ATAAD, 12 studies, 1,300 patients) versus nonacute Type A dissection and aneurysm (14 studies, 741 patients), mortality was 9.2% in ATAAD versus 7.6% in non-ATAAD ($p = 0.46$).[26] This subgroup mortality rate is almost identical to the FET mortality (7.7%) and less than the cET mortality (14.5%) presented in a separate 2018 systematic review (12 studies, 1,803 patients).[10] Similarly, a recent meta-analysis by Vernice et al[31] has supported the mentioned results. The authors showed that FET had lower perioperative mortality (relative risk: 0.50, 95% CI: [0.42; 0.60], $p < 0.001$) and improved 1-year survival compared with cET (hazard ratio [HR]: 0.63, 95% CI: [0.42; 0.95], $p = 0.03$).[31]

Stroke incidence is lower with FET. Preventza et al[30] found a 7.6% (95% CI: 5.0–11.5, $I^2 = 88.3\%$) pooled estimate for transient or permanent stroke in FET; accounting for the high heterogeneity, the 95% confidence interval was 2.9 to 12.3%.[30] Similarly, Hanif et al[10] presented an improved FET stroke rate of 6.5% (odds ratio [OR]: 0.78; 95% CI: 0.52–1.15, $p = 0.21$, $I^2 = 0\%$) compared with the cET stroke rate of 9.7%. It

Table 2 Summary of the characteristics and technical specifications of commercially available FET grafts

Device	Thoraflex hybrid	E-Vita Open	Frozenix	Cronus Open
Manufacturer	Terumo Aortic	Jotec	Japan Lifeline	Microport
Year of introduction	2012	2008	2014	2003
Market penetration	Global (Europe, Asia, Canada, United States)	Europe, Asia	Japan	South America, Asia
Material	Nitinol	Nitinol	Nitinol (2-layer)	Conichrome
Stent design	Ring	Z-shape	Oval	Z-shape
Arch reconstruction strategy	Quadrifurcated graft	Island technique reconstruction or separate graft arch graft	Separate graft arch graft	
Proximal diameter (mm)	22–32	20–40[a]	17–39	21–32
Distal diameter (mm)	24–40			
Stent graft length (mm)	100 or 150	120–130 or 175–180	60, 90, and 120	40–150
Full device length (mm)	340 or 390	180, 220 or 230	570	150–200

Abbreviations: CA, celiac axis; DTA, distal thoracic aorta; ATAAD, acute Type A aortic dissection; DTA, distal thoracic aorta; FET, frozen elephant trunk; LSA, left subclavian artery.
Source: Reviewed in further depth by Chauvette et. al.[24]
[a]Available in different proximal and distal configurations.

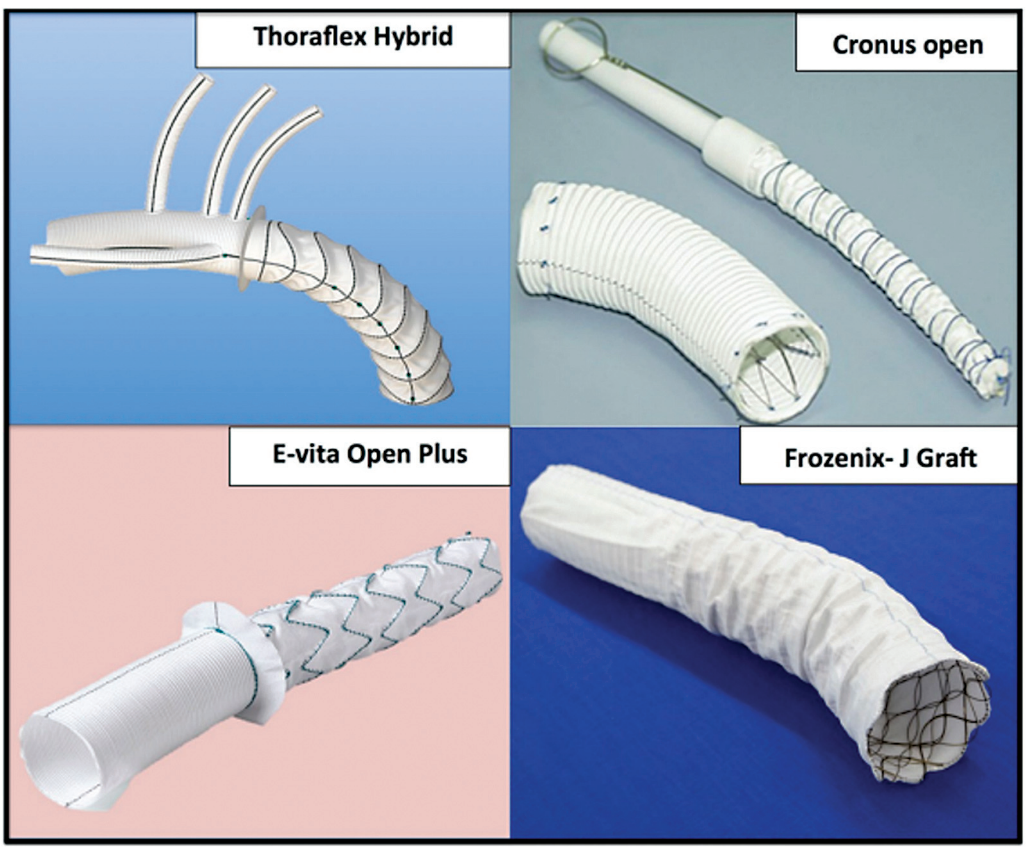

Fig. 3 Current available FET stent grafts available commercially. Reproduced from Di Bartolomeo et al.[29] Copyright permission to reuse had been obtained from Springer Nature.

is possible that the FET stroke rate is lower in the meta-analysis by Hanif et al[10] due to their inclusion of both total aortic replacement (TAR) and proximal/hemiarch procedures. When dividing the ATAAD studies and nonacute Type A dissection and aneurysm studies, respective stroke incidence was 9.3 versus 6.6% ($p = 0.51$).[30]

FET is believed to be associated with higher rates of spinal cord ischemia than cET. Based on meta-analyses alone, rates of spinal cord ischemia (SCI) remain greater in FET patients than in cET patients. Hanif et al[10] found a pooled OR estimate of 2.20 (95% CI: 1.10–4.37, $p = 0.023$) in favor of cET (2.6% SCI) versus FET (5% SCI) across nine studies, which is similar to the 4.7% SCI (95% CI: 3.5–6.2, $I^2 = 46.3\%$) reported for FET by Preventza et al.[30] It must be considered that meta-analyses are inherently limited in the reporting of surgical data. At present, no definite conclusion can be reached due to the lack of direct comparison in a single-center setting, and the performance of the grafts in reducing SCI is possibly related to the complexity of the aortic pathology. However, it is promising that a recent multicenter study demonstrated that FET does not increase the incidence of paraplegia in patients with ATAAD.[32] The FET procedure combines repair of ascending, transverse and proximal DTA, offering more technical demand and complexity to the procedure when compared with cET. In terms of operative data, a recent meta-analysis by Vernice et al[31] showed that the FET procedure was associated with a significantly longer time of antegrade cerebral perfusion (51.08 vs. 69.2 minutes; $p < 0.0001$) and circulatory arrest time (47.6 vs. 53.3 minutes; $p < 0.0001$). In the same metanalysis, however, FET was shown a significantly lower time of the overall bypass (226.1 vs. 229.1 minutes; $p = 0.0006$) and cross-clamp (126.8 vs. 114.9 minutes; $p < 0.0001$) time.[31] Moreover, two recent metanalyses showed no evidence of a significant difference in the incidence of major bleeding or open reintervention between the two techniques.[10,31]

Acute Dissection

Acute Type A Dissection

There is a large ongoing debate concerning the most appropriate management of the aortic arch in ATAAD, and particularly, around whether the FET technique should be used routinely to treat these patients. Studies that offer evidence on this debate are included in ►**Table 3**.[33–40] The aforementioned meta-analysis by Preventza et al[30] identified 12 studies (1,300 patients) in which patients underwent FET for emergency repair of ATAAD. Mortality and stroke were 9.2 and 9.3% compared with the 7.6 and 6.6% mortality found in studies with nonacute Type A dissection and aneurysm (14 studies and 741 patients; $p = 0.46$ and $p = 0.51$). These findings are similar to what was identified in a 2016 meta-analysis by Takagi and Umemoto[41] which also exclusively studied FET in ATAAD, finding early mortality of 9.2% (95% CI: 7.7–11.0%) and stroke of 4.8% (95% CI: 2.5–9.0%). Improved prevention strategies against adverse outcomes are warranted and will become better understood as more independent risk factors are identified in the ATAAD context.

Table 3 FET outcomes in ATAAD

First author	Year	Sample size	Major device(s)	Short-term outcomes			Long-term outcomes			
				In-hospital mortality (%)	Stroke	Spinal cord injury (%)	Survival (%)	Freedom from reintervention (%)	FL thrombosis (%)	
									Arch	DTA
Mehanna et al[33]	2021	8	Thoraflex Hybrid	–	9	–	–	–	Preoperative vs post-operative ratio between false lumen and total aortic lumen: 0.63 (0.13–0.8) vs. 0.45 (0.15–0.65)	
Usai et al[34]	2021	20	Thoraflex Hybrid	4.6	–	–	–	–	2 y: Insignificant difference in mean FL volume between LSA and CA	
Yoshitake et al[54]	2020	139	J-Graft Open	1.4	5	0.7	3 y: 95.0 5 y: 93.0	3 y: 87.7 5 y: 84.9	87.8[e]	
Liu et al[36]	2020	154	Cronus	5.2	3.9	–	2 y: ±90	–	6 mo: 92.4	6 mo: 74.3
Liu et al[35]	2020	300	Cronus	6.7	4.0	–	–	–	–	–
Kaneyuki et al[53]	2020	32	J-Graft Open; J-Graft Frozenix	13.0	–	3	3 y: 76.6	3 y: 96.6	1 y: 89	1 y: 67

Table 3 (*Continued*)

First author	Year	Sample size	Major device(s)	Short-term outcomes			Long-term outcomes			
				In-hospital mortality (%)	Stroke	Spinal cord injury (%)	Survival (%)	Freedom from reintervention (%)	FL thrombosis (%)	
									Arch	DTA
Furutachi et al[37]	2019	20	J-Graft Frozenix	5.0	0	0	–	–	–	–
Berger et al[18]	2019	55[a]	Thoraflex Hybrid	11	16	6	–	1 y: 78	6 mo: 63 1 y: 74	6 mo: 30 1 y: 53
		33[a]	E-Vita Open	12	7	6	-	1 y: 100	6 mo: 80 1 y: 95	6 mo: 48 1 y: 80
Inoue et al[52]	2019	33	J-Graft Frozenix	6.1	–	0	–	–	2 y: 87–93%	2 y: 70
Roselli et al[38]	2018	72	Modified C-TAG (Gore Medical)	4.2	8	4.2	1 y: 92 3 y: 89 5 y: 80	1 y: 87 3 y: 77 5 y: 72	2 y: 92	2 y: 54
Iafrancesco et al[50]	2017	61	E-Vita Open	–	–	3.6[a]	5 y: 100	3 y: 100 5 y: 96	1 y: 100	See study
Shrestha et al[39]	2017	96	Thoraflex Hybrid	5.9[b]	17	3.9[b]	5 y: 75[c]	5 y: 90	–	–
Shrestha et al[17]	2016	37	Thoraflex Hybrid	8	16	8	3 y: 92	3 y: 92	Remodeling of the stented segment of the descending aorta is faster to thrombose in AAD versus CAD, with FL thrombosis achieved in 100% of patients at 2 y.	
Dohle et al[40]	2016	70[d]	E-Vita Open	10	–	–	–	–	1 y, Stent graft: 90 1 y, Distal: 65	
Leontyev et al[25]	2016	170	E-Vita Open	17.1	11.8	6.5	–	–	-	
Ius et al[45]	2013	35	Thoraflex Hybrid	17	17	0	1 y: 77 ± 7	1 y: 73 ± 8	Subclavian artery: 87 Pulmonary artery: 75	
		30	E-Vita Open	20	10	0	1 y: 73 ± 8	1 y: 87 ± 7	Subclavian artery: 100 Pulmonary artery: 90	
		66	Chavan Haverich Custom	9	8	2	1 y: 88 ± 4	1 y: 83 ± 5	Subclavian artery: 93 Pulmonary artery: 82	

Abbreviations: CA, celiac axis; DTA, distal thoracic aorta; ATAAD, acute Type A aortic dissection; DTA, distal thoracic aorta; FET, frozen elephant trunk; LSA, left subclavian artery; SCI, Spinal cord injury
[a]Pooled injury from acute and chronic dissections.
[b]Represents proportions in contemporary cohort ($n = 119$) exclusively treated with Thoraflex Hybrid.
[c]Estimated from Kaplan–Meier curve.
[d]Represents total number of acute dissections.
[e]At level of bronchial carina.

Recently, the duration of cardiopulmonary bypass (CPB) was identified as an independent predictor of adverse outcomes in surgical repair for ATAAD.[42]

Influencing the prognosis of ATAAD is end-organ malperfusion, which affects approximately one-third of patients and dramatically impairing the outcome, increasing the mortality from 6 to 15% when absent, to 40 to 50% when it onsets.[43] Moreover, extensive involvement of the aorta puts patients at higher risk for late complications secondary to the aneurysmal degeneration of the distal aorta. In both instances of extensive aortic involvement and visceral organ malperfusion, the placement of a stent graft in the descending thoracic aorta, as done with FET, compared with simple ascending aorta or hemiarch replacement, favors the opening of the true lumen and the obliteration of the secondary entry tears and promotes FL thrombosis with more timely reversal of the malperfusion process. This leads to reduced rates of late distal reintervention and death from aortic rupture. The more complete aortic remodeling may be reflected in complete FL thrombosis and decrease/elimination of the TL diameter.

Frozen Elephant Trunk Leads to Superior Aortic Remodeling than Conventional Elephant Trunk in the Acute Setting

Partial or complete FL thrombosis at the level of the stent graft occurs in ± 90% of ATAAD treated with FET,[43,44] accompanied by further downstream FL shrinkage. Nonetheless, despite being superior, the distal FL shrinkage may still be incomplete or unsatisfactory and requires careful surveillance.[45–48]

FET is also more capable than cET of thrombosing the FL to a more distal level.[44,49–51] The reported failures of cET to address residual FL patency in the distal aorta may therefore facilitate aortic enlargement[52,53] and pose a greater risk of later additional distal aortic surgery. At the level of the distal arch and distal edge of the endograft, Inoue et al[52] observed insignificantly different postoperative FL patency between FET ($n = 33$) and cET ($n = 115$) groups ($p = 0.73$ at the distal arch and $p = 0.71$ at the distal edge of the ET). Median follow-up was 2 years.[52] For both groups, postoperative FL patency was only 7 to 13% at the distal arch, which was a significant decrease from the FL patency that was observed preoperatively.[52] Differences between FET and cET became apparent at the level of the left lower pulmonary vein (LLPV). In the FET group, the change in postoperative FL patency at that level was substantially lower (73% preoperative vs. 30% postoperative) than in the cET group (84% preoperative vs. 77% postoperative).[52] Reflectively, all aortic segments studied from the FET group showed a trend to decline between 1 and 6 months time point, whereas the size of the aortic segments showed a tendency to increase in the cET group at both LLPV and celiac axis (CA).[52]

A more recent retrospective study of similar nature by Kaneyuki et al[53] compared outcomes of FET ($n = 32$) versus cET ($n = 17$) in a cohort of retrograde ATAAD patients. Median CT follow-up was 1 year.[53] Again, better remodeling was achieved with FET, although the findings are in conflict with those presented by Inoue et al[52] Unlike Inoue et al,[52] who show that remodeling benefits achieved with FET are achieved in the downstream distal aorta (at LLPV and CA), Kaneyuki et al[53] show that remodeling benefits achieved with FET are more apparent at the level of the distal arch. At this anatomical level, they found that only 11% of FET patients had FL patency, compared with only 54% of the cET patients ($p = 0.042$).[53] However, more downstream, FL patency appeared to remain consistent in the cET group but increase in the FET group.[53] At the level of the LLPV and CA, FL patency was found in 48 and 63% of the FET group, whereas the cET group remained at 54% at both anatomical levels (LLPV, $p = 0.74$; CA, $p = 0.58$).[53] Given the relatively smaller cET sample size ($n = 17$) compared with Inoue et al,[52] it is highly possible that their analysis was underpowered.[53] Additionally, the authors also outline that the procedures were performed in different years, which possibly introduced selection bias amongst the surgeons.[53]

FET also appears to offer superior remodeling to other conventional arch repair strategies, such as partial arch repair ± stent graft and hemiarch repair ± stent graft. A 2020 study by Yoshitake et al[54] compared FET ($n = 139$ patients) to a conventional arch repair cohort ($n = 287$) undergoing ATAAD repair. FL thrombosis at the level of the bronchial carina was achieved in 87.8% of FET patients but only 58.6% of non-FET patients.[54] Respective survival rates at 3 and 5 years postoperatively were 95.0 ± 5.1 and 93.0 ± 7.0% in the FET group and 85.3 ± 14.8 and 80.8 ± 19.2% in the no FET group.[54] When propensity matching (PMS), 92 patients each from the FET and non-FET cohorts, there was 85.1 versus 39.5% FL thrombosis. It is interesting that PMS found an insignificant difference in 3 year rate of freedom from distal thoracic aortic reintervention, estimated with Kaplan–Meier (89.0 ± 11.0% in FET and 87.5 ± 12.5% in non-FET group, $p = 0.966$).[54] However, long-term survival and rates of freedom from aortic-related death were superior under FET versus non-FET ($p = 0.013$ and $p = 0.044$, respectively).[54]

Acute Type B Dissection

TEVAR remains the first-choice treatment for acute Type B aortic dissection (ATBAD) that are complicated and require care beyond medical management. However, these patients remain at risk as there is still a persistent risk of retrograde Type A aortic dissection (TAAD). The FET technique represents an alternative when no "landing zone" is present for TEVAR or if there is a concomitant aneurysm of the aortic arch/ascending aorta, and when there is steep arch angulation. A recent study by Matsuzaki et al[55] compared 17 patients who underwent total arch replacement using frozen elephant trunk (TAR-FET) (Frozenix) for acute exacerbation of uncomplicated TBAD, in whom TEVAR was anatomically contraindicated, with a subgroup of 16 elderly patients undergoing Zone 2 TEVAR. Mean follow-up was 15.8 ± 9.7 months. The mean age in the TAR-FET group was significantly lower (67 vs. 76 years; $p = 0.02$) and the maximum diameter of the ascending arch was significantly larger in the TAR-FET group (46 vs. 37 mm; $p = 0.001$). There was zero in-hospital- and late mortality in both groups. Spinal cord ischemia and stroke occurred in zero TAR-FET group, but both occurred in one (6%) of the TEVAR group. This sample is too small to make reliable deductions but is sufficient to

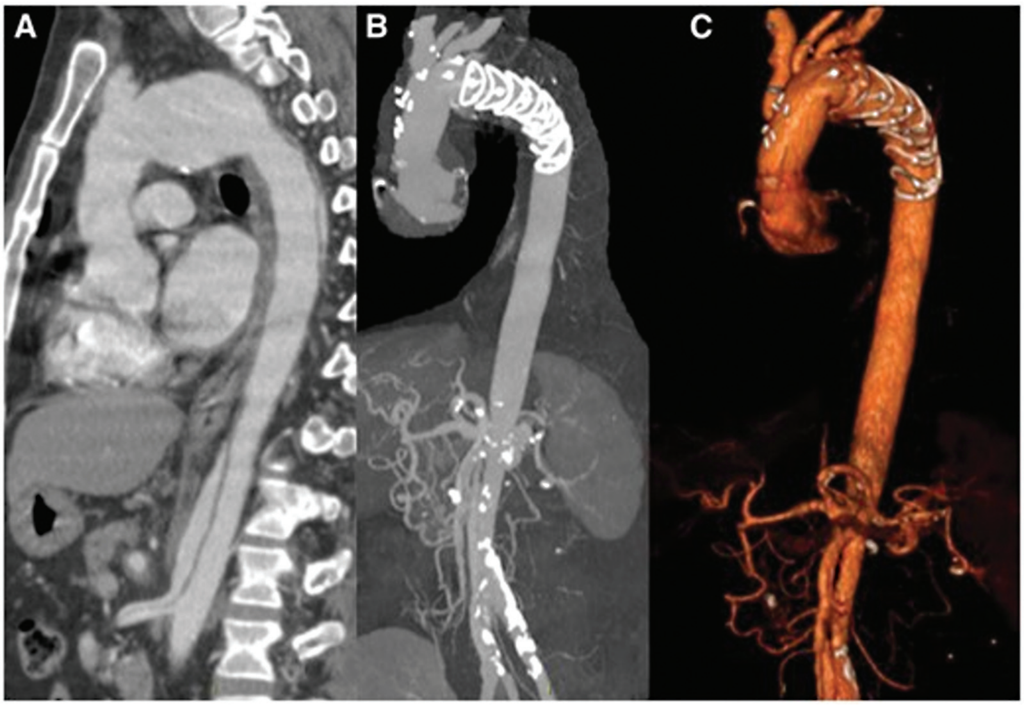

Fig. 4 (**A**) Preoperative angio-CT scan showing an ATBAD with an intimal tear located at the aortic isthmus. (**B, C**) Postoperative final result after FET surgery. Reproduced from Di Bartolomeo et al.[24] Copyright permission to reuse had been obtained from Oxford Academic Group.

illustrate that TAR-FET is an adequate substitute for TEVAR in the short- and midterm for certain cases. ►**Fig. 4** shows preoperative angio-CT scan showing an ATBAD and a postoperative scan after the FET procedure.

A 2015 analysis from the International E-vita Open Registry by Weiss et al[56] included 57 TBAD patients—28% were acute ($n = 16$) and 72% were chronic ($n = 41$). In the majority of cases, the aortic arch and/or ascending aorta had aneurysmatic dimensions or was retrogradely involved by the dissection and required concomitant treatment. In total, 54 (95%) and 38 patients (67%) underwent replacement of the aortic arch and/or the ascending aorta, respectively. Overall, in-hospital mortality rate was 14% (8/57) or 13% of acute TBAD patients (2/16) and 15% of chronic TBAD patients (6/41). Pooled stroke and spinal cord injury (SCI) were 10 and 4%.[56] The authors attribute the elevated stroke rate to the arch replacement procedure rather than to the stent graft itself, as the time for stent-graft placement and deployment did not prolong the period of antegrade selective cerebral perfusion or hypothermic circulatory arrest when compared with cET total arch replacement.[56] Before discharge, the rate of immediate FL thrombosis at the level of the stent graft was 79% in ATBAD and 74% in chronic Type B aortic dissection (CTBAD). Better complete FL thrombosis was seen with ATBAD than CTBAD in the distal thoracic descending aorta (36% ATBAD vs. 28% CTBAD) and abdominal aorta (28% ATBAD vs. 5% CTBAD). These trends were similar at a mean follow-up of 23 ± 19 months and are illustrated in ►**Table 4**.[56] At follow-up, distal to the stent graft, there was 50% FL patency in all patients (33% ATBAD vs. 57% CTBAD), which poses a risk of late aortic growth and aneurysm formation. Patency was likely higher in the CTBAD group due to preexisting FL origins of visceral, renal, or intercostal arteries. Secondary endovascular intervention was necessary in only 12% of patients due to disease progression. The 1- and 3-year survival was 81 and 75%, respectively.[56]

Chronic Dissection with Degenerative Aneurysms

Directly comparing FET to cET for chronic dissection and aneurysmal disease is not straightforward due to heterogeneous sample sizing. For instance, of the 58 chronic aortic dissections (pooled Type A and B dissections) patients studied by Shrestha et al[4] 7 underwent cET while 51 underwent FET. This is reflective of the progressive adoption of FET into surgical practice.

Chronic Type A Aortic Dissection

ATAAD requires an emergency operation to save the life of the patient. Aortic remodeling remains a secondary target, and a considerable proportion of acute aortic dissection cases are left with residual disease and FL patency and remain at risk for late aneurysmal degeneration.[57–59] Approximately 60% of patients who survive surgical treatment for ATAAD will require aortic reintervention.[60] The optimal treatment modality for Chronic Type A Aortic Dissection (CTAAD) remains to be established. Only a small number of series exist which have analyzed the outcomes of the FET procedure in chronic TAAD patients. These have been summarized in ►**Table 5**.[61–66] The FET procedure is desirable in these patients because of its ability to exclude more distal entry tears. The quadrifurcated shape of the Thoraflex Hybrid is ideal, as it even allows the surgical exclusion of dissections of the supra-aortic vessels.

Table 4 Recent cET and FET comparison studies in the context of ATAAD repair

First author	Year	Follow up (years)	Procedure	Variable								
				Sample size	Technical success (%)	30-d mortality (%)	Stroke (%)	Spinal cord injury (%)	FL thrombosis (%)		dSINE (%)	Freedom from reintervention (%)
									Arch	DTA		
Kaneyuki et al[53]	2020	Clinical: 2 CT: 1	FET	32	–	13	–	3	89	52	–	3 y: 96.6
			cET	17	–	6	–	0	46	46	–	3 y: 68.8
Furutachi et al[37]	2019	1	FET	20	100	5	0	0	68	47	16	–
			cET	30	73	10	7	7	56	37	–	–
Inoue et al[52]	2019	2	FET	33	100	6	–	0	70[a]		–	–
			cET	115	100	5	–	0	37[a]		–	–

Abbreviations: ATAAD, acute Type A aortic dissection; cET, conventional elephant trunk; CT, computed tomography; dSINE, Distal stent-graft induced new entry; DTA, distal thoracic aorta; FET, frozen elephant trunk.
Note: FET shows superior aortic remodeling (as seen through results of FL thrombosis).
[a]At level of lower left pulmonary vein.

Echoing the data from Weiss et al,[56] ►**Table 6** which highlights better remodeling in acute versus chronic dissection, Iafrancesco et al[50] similarly analyzed 137 patients from the International E-vita Open Registry. The majority of patients had TAAD. There were 65 acute dissections (ATAAD, $n = 61$ [44.5%]; ATBAD, $n = 4$ [2.9%]) and 72 chronic dissections (CTAAD, $n = 51$ [37.2%]; CTBAD, $n = 21$ (15.3%)).[50] Median follow-up was 32 months (IQR, 21–53 months). Similar for both acute and chronic dissections, the rate of FL thrombosis was higher in the middescending thoracic aorta (99.3%) and lower in the distal abdominal aorta (13.9%). Their results also illustrated that the chronic group exhibited a higher rate of negative remodeling in the downstream thoracic aorta (33 vs. 17.5%, $p = 0.040$).[50] Negative remodeling refers to a significant increase in the diameter of the aortic lumen or a significant decrease in the diameter of the true lumen. A total of 23 (16.8%) patients had reintervention on the distal aorta, but only one patient underwent distal reintervention in the acute dissection group. One-, 3-, and 5-year estimates of freedom from distal reintervention were statistically different between the acute and chronic groups, which were, respectively, 100 and 100%, 96.3 and 84.7%, 79.7 and 64.3% ($p < 0.001$).[50]

The abdominal aortic diameter usually remains stable or undergoes further expansion at follow-up following FET repair. In a cohort of chronic aortic dissection patients undergoing FET repair, a significant increase in the abdominal aortic diameter at the celiac trunk after 2 years was observed (36 ± 8 vs. 43 ± 8 mm, $p = 0.033$) with no significant change in the FL diameter.[67] The reported data were inconclusive when comparing the effectiveness of the repair in the acute versus chronic phase of the disease. Yet, the chronic groups seemed to have inferior outcomes and required more later reintervention. The difference in rates of FL thrombosis for FET versus cET favored the FET group over the cET group (87.8 vs. 58.6%; $p < 0.01$).[54] Still, this comparison is limited, given the inconsistent indications for second-stage stenting in cET.

Chronic Acute Type B Aortic Dissection

Patients with CTBAD are generally young and are usually afflicted with connective tissue disorders. Staged cET procedures have previously been used to treat extensive aortic aneurysms. Some have suggested that the intimal membrane should be fenestrated to a length corresponding at least to the ET prosthesis to avoid its entrapment and equalize perfusion in both the true and false lumina to improve outcomes.[9,68–73] However, FET has recently experienced increased application in chronic dissection patients for its better capability in remodeling the distal aorta.[4,52,74] FET is also a reasonable option to treat CTBAD with arch involvement, as it is able to avoid kinking and graft obstruction associated with cET, as well as interval mortality incurred due to rupture of the remaining aorta[75,76] between stage I and stage II..

Studies reporting on FET for CTBAD indicate in-hospital mortality and stroke rates both between 0 and 12% and SCI between 0 and 9%[4,77–79] (►**Table 5**). The aforementioned study by Weiss et al[56] from the international E-Vita Open registry demonstrates similar interim outcomes of mortality,

Table 5 Series reporting on FET-treated chronic TAAD and/or TBAD.

First author	Year	Procedure	Sample size		Main device used	Mortality (%)		Spinal cord ischemia or paraparesis (%)	Stroke (%)	Freedom from distal reintervention (%)	Complete FL thrombosis (%) at follow up
			CTAAD	CTBAD		In-hospital	30-day				
Luo et al[61]	2021	FET	0	19	Cronus	5.3	–	5.3	5.3	1 y: 97.3 3 y: 87.8 5 y: 84.3 7 y: 79.3	–
Beckmann et al[62]	2020	FET	47		Thoraflex Hybrid	11	11	4	19	2 y: 74	–
Kreibich et al[63]	2020	FET	0	12	Thoraflex Hybrid	0	–	0	0	39[a]	–
Chen et al[64]	2020	FET	68	0	Cronus	13	–	0	0	1 y: 96.6 5 y: 90.2 10 y: 82.0 12 y: 82.0	Proximal end of FET: 100 Distal end of FET: 88.5 Unstented descending aorta: 46.2 Diaphragmatic hiatus: 26.9
Charchyan et al[65]	2020	FET	0	20	E-Vita Open	0	0	0	0	2 y: 89	Proximal DTA: 100 Distal DTA: 88.2 Level of visceral branches: 17.6
Yamane et al[66]	2020	FET	15	0	Frozenix	6.7	–	0	6.7	–	Stent graft: 100 Distal to stent graft: 77.8
Shrestha et al[4]	2015	FET	51		Thoraflex Hybrid	–	8	2	12	–	–
		cET	7		–	–	14	0	0	–	–
Weiss et al[56]	2015	FET	0	41	E-Vita Open	15	–	5	10	2 y: 80 3 y: 65	Stent graft: 97 DTA: 53
Di Eusanio et al[79]	2011	FET	39	10	E-Vita Open	10.2	–	6.1	0	77.6	Stent graft: 82.9 Distal: 43.9
Pacini et al[78]	2011	FET	69	21	E-Vita Open	12	–	4	1	4 y: 96 ± 3	–
Sun et al[46]	2011	FET	143	–	Cronus	1.4	–	2.8	2.1	2 y: 96.2	2 y: 92.0
		CSR	54			3.7	–	0	0	2 y: 97.2	2 y: 10.3
Sun et al[77]	2010	FET	0	19	Cronus	–	5.3	0	0	–	Stent graft: 94.1 Diaphragm: 41.2 Descending aorta: 29.4

Abbreviations: CSR: conventional surgical repair; CTBAD, chronic Type B aortic dissection; FET, frozen elephant trunk.
[a]Includes CSR.

Table 6 Remodeling of the aorta post-FET in ATBAD and CTBAD patients

Before discharge				
Complete FL thrombosis (%)	**Overall[a] ($n=53$)**	**ATBAD[a] ($n=14$)**	**CTBAD[a] ($n=39$)**	**ATBAD[50,b] ($n=17$)**
Stent graft	75	79	74	87
Distal descending thoracic aorta	30	36	28	75
Abdominal aorta	11	28	5	6
At follow-up				
Complete FL thrombosis	Overall[a] ($n=42$)	ATBAD[a] ($n=12$)	CTBAD[a] ($n=30$)	ATBAD[50 b] ($n=17$)
Stent graft	98	100	97	93
Distal descending thoracic aorta	60	75	53	87
Abdominal aorta	19	33	13	0

Abbreviations: ATBAD, acute Type B aortic dissection; CTBAD, chronic Type B aortic dissection; FET, frozen elephant trunk.
Source: Summarized data from Weiss et al[51,a], or Matsuzaki et al[50,b] where indicated.
[a]Mean follow-up of 23 ± 19 mo.
[b]Mean follow-up of 15.8 ± 9.7 mo.

stroke, SCI, and renal failure in ATBAD versus CTBAD. As demonstrated in ►**Table 6**, even the interim FL thrombosis is similar; but, over follow up, there is clearly superior downstream remodeling in the ATBAD group. Of the chronic/aneurysmal cohort, the most affected group were chronic TAAD (10.9% spinal cord injury, SCI) and least affected were chronic TBAD (2% SCI).[56] It is known that there is elevated SCI risk when endovascularly landing below Th10,[23] and one possible strategy to reduce SCI (to $< 0.5\%$) is to perform FET only on patients whose aneurysm can be entirely treated by the length of the stent graft.[54]

In rare cases where cET surgery is preferred, completing both stages is essential for improving long-term survival.[8] Castrovinci et al[8] demonstrated that overall survival after first stage cET was 75 and 67% at 5- and 10-years follow-up, respectively. Survival in the group with second stage cET was 87%, compared with 65% in the group who had not undergone the second stage at the 5-year follow-up ($p < 0.001$), and 67% compared with 36% at the 10-year follow-up (log-rank, $p < 0.001$).[8] The $< 10\%$ mortality reported after first-stage cET is adequate to facilitate future open or endovascular TA repair of the distal aorta.[8,22,72] In second-stage patients, perioperative mortality was 9% in those undergoing open repair and only 4% in those undergoing endovascular treatment.[8] A more recent study found that in-hospital mortality rate was significantly lower in the FET (8%) group compared with the cET group (29%; $p = 0.045$) when conducting second stage repair. Further highlighting the superiority of endovascular completion via FET over second-stage cET is that 5-year survival rate was 76% in the cET patients versus 89% in the FET patients (log-rank: $p = 0.11$).[80]

Distal Aorta Considerations

The distal aorta of chronic dissection patients is often complex. The true lumen may be small and compressed by the FL. The dissection flap could be thick and stiff, and this poor pliability coupled with aortic tortuosity may cause the junction between the aortic arch and descending aorta to kink. Kinking and graft-entrapment during first stage cET could cause a pseudocoarctation.[1]

The False Lumen

The stent graft provides a positive remodeling with rates $> 90\%$ at the level of FET in the first year after repair.[44,49] However, the downstream aorta does not seem to possess the same ability to remodel. It either stabilizes or undergoes negative remodeling with aortic expansion. This is especially evident in cases with distal FL patency, whose rates remained high over varying follow-up periods.[40,50,67] Dohle and colleagues[40] have reported a 92% FL thrombosis in the stented segment after 1 year of follow-up. In contrast, the FL thrombosis was only 29% downstream in the stent to the celiac trunk. Moreover, FL thrombosis extending below the celiac trunk was observed in only 25% after the first year of follow-up. Iafrancesco et al[50] showed that the rate of FL patency at the celiac trunk was 71.6% at a median of 32 months. Similarly, Weiss et al[81] reported an FL patency rate of 52 and 78% at the level of the diaphragm and celiac trunk, respectively. The very downstream segments of the aorta were reported to go under no change following the procedure.

Reinterventions for Distal Repair

The negative remodeling downstream of the FET stent often warrants later reintervention for supplemental distal aortic repair. In both acute and chronic aortic dissections, the need for reintervention was significantly correlated with the FL patency downstream in the aorta. The FET approach provides a suitable landing zone for endovascular repair and facilitates downstream procedures on the aorta. Most of the reinterventions were indicated for patients with high rates of negative downstream remodeling. Further, the timing for reintervention varied between patients, reflecting our limited understanding of the course of distal aortic remodeling.[40] Total descending aorta retreatment following FET was reported as high as 48.2% ($n = 28$) with 29.3% of them having open surgical reoperation.[82] Dohle et al[40] performed 3/46 reinterventions in the acute (1 open and 2 TEVAR) and 5/22 in the chronic (2 open and 3 TEVAR) phase for distal aortic repair. Berger et al[67] reported an overall reintervention rate of 28% in the downstream aorta at 12 ± 12 months. The reintervention rate in acute AD was 19% (6/31) and all of them underwent TEVAR. In contrast, the reintervention rate in chronic AD was 32% (11/34), and six patients underwent TEVAR, while the rest had classic open replacement.[67] Another observation by Iafrancesco and colleagues[50] showed a reintervention rate of 16.8% for distal aortic repair, of whom 12.4% underwent endovascular repair with the rest having an open thoracoabdominal repair. Strict follow-up is paramount to detect early changes in the aortic dimensions, which may warrant further intervention.

Predictors for Late Reinterventions

Preoperative data have been used to predict the incidence of post-FET distal dilatation and the need for late reintervention in the downstream aorta. Fattouch et al[82] showed that patent FL, Marfan syndrome, and maximum descending aortic diameter > 4.5 cm were significant predictors for reintervention following FET.

In a cohort of patients with Marfan syndrome who underwent FET aortic repair, the preoperative maximal aortic size was shown to be a predictor of later distal dilation (HR, 1.11) and reoperation (HR, 1.07).[83] Chen et al[83] proposed to lengthen the stent portion into the middescending aorta to improve the high probability of late distal dilation. Still, this requires a nuanced approach and careful selection of patients among those with Marfan or connective tissue disease. It is critical to consider the risk of SCI associated with longer stents.[83] We believe that distal aorta considerations should be given greater weight in perioperative planning. Patients with chronic dissection were shown to have a worse prognosis in terms of distal aortic dilation, with a larger proportion requiring reintervention when compared with the acute group.[84] A prophylactic cET proposed by Idrees et al[84] showed encouraging results to mitigate the late risks associated with a moderately dilated distal aorta at presentation. Such an aggressive approach would buffer the late risks by preparing for follow-up interventions with endovascular or open repair in selected cases.

Broader Potential of Frozen Elephant Trunk

Zone 0

Landing zone 3 was the traditional site of proximal anastomosis of the stent graft in FET repair. This was followed by a gradual shifting toward landing zone 2, as it favors more accessible field and superior outcomes.[23] Recent evidence has showed that shifting toward landing zone 0 was associated with even better surgical accessibility and lower perioperative complications.[85] Compared with zone 2, proximal stent landing in zone 0 was associated with less CPB, cardioplegia, and cerebral perfusion time[85] However, no evidence if available as to if this would lower the chance of thrombosis (remodeling) and lead to increased need for reoperation. Further, there were lower rates of spinal, renal, and recurrent laryngeal nerve injury.[85] The survival and need for reintervention also appears to favor zone 0 over zone 2 FET aortic repair[85]. The rate of reintervention reported by Yamamoto et al[86] following zone 0 proximal stenting using FET (Frozenix) was 5.8, 9.1, and 9.1% at 1, 2, and 3 years, respectively. The fate of the FL was unfavorable in the distal aorta; FL thrombosis in the DTA was achieved in 29.6% ($n = 32$) and 5.5% ($n = 6$) in the abdominal aorta. Further, they reported three cases with reopening of FL around the celiac trunk following zone 0 FET repair.[86]

Branched Frozen Elephant Trunk

The latest introduction among trunk prostheses is the branched-FET. Uniquely, it affords the flexibility to easily achieve[1] distal arch anastomosis,[2] rapid distal organ reperfusion, and[3] individual epiaortic vessel reimplantation.[87] This provides an advantage over the nonbranched approach, especially in cases where the epiaortic vessels are involved in the dissection. Further, these measures have substantially contributed to shortening the ischemic time of the myocardium, spinal cord, and visceral organs.[87]

Who will cET Continue to Benefit?

The inception and progressive adoption of FET in the field of aortic surgery has encroached substantially on cET. The literature over the last decade is dominated by FET studies. FET has a broad scope in treating thoracoabdominal disease, and it is even starting to be used effectively for patients with connective tissue disorders. Not all pathologies of the arch are the same, and there are no standard surgical protocols for ET placement, leaving most aortic centers to adopt their own surgical strategy.

FET can be applied to almost all multi-segmented thoracic aortic pathologies, with the exception of descending aortic free rupture, mycotic aneurysms, and severe aortic isthmus stenosis.[87] Applicable settings include emergency ATAAD repair, atherosclerotic aneurysms in downstream segments, post-dissection aneurysms of progressing diameter, giant cell aortitis with aneurysm formation, and mega-aortic syndrome.[88,89] Besides providing the option of treating a distally extended aortic arch disease in one stage via a single median sternotomy, FET allows for the exclusion of the proximal segment of an otherwise extensive thoracic / thoracoabdominal aortic disease. However, in the absence of objective results from randomized controlled trials, FET cannot be justified as the universal treatment. Case series are not entirely comparable due to variable population characteristics and operative indications. However, current trends in the literature would affirm that the "elephant trunk is freezing"[4].

The obvious advantages of FET are its potential to be completed in a single stage, and its ability to surgically repair thoracoabdominal lesions in patients that have tight angulation at the distal arch that may put the conventional elephant trunk surgical graft at risk for kinking or partial compression. The FET approach also provides a suitable landing zone for endovascular repair and facilitates downstream procedures on the aorta. However, FET remains limited by its high incidence of SCI. Keeping the stent graft above the Th9 level is a common strategy to reduce SCI risk when performing FET. The potential pathogenic mechanisms for SCI post-FET include circulatory arrest, coverage of the intercostal arteries, embolization, and postoperative periods of hypotension. To avoid these complications, the Bologna group[5] uses moderate hypothermia, total brain perfusion with perfusion of the left subclavian artery, lower body perfusion to reduce the duration of circulatory arrest, cerebrospinal liquor drainage, and maintenance of postoperative stable hemodynamics with a mean arterial pressure greater than 80 mm Hg. SCI risk could also possibly be reduced through using deeper levels of hypothermia and shorter stent grafts, although there will likely be distal reinterventions and deep hypothermia-related complications that may emerge from this. Aortic devices could be modified to achieve anastomosis at faster speed, although these modifications cannot be expected to enter the surgical armamentarium for some time. A separate issue involves the use of FET in ATAAD for patients with connective tissue disorders, such as Marfan syndrome. For such patients with a fragile and thin aortic wall, limited use of TEVAR is advised.[90] Therefore, while the use of FET in these circumstances is also controversial, it has been achieved.[64,83,91] Chen et al[83] retrospectively reviewed TAR-FET in a young (mean age $\pm$ 34 years) Marfan cohort (94 acute, 78 chronic, 172 total). For the 94 patients with acute dissection, an acceptable early mortality rate of 7% was achieved with 3 and 2% for stroke and SCI.[83] In the entire cohort, 8-year incidence of death was 15%, reoperation rate was 20%, and event-free survival was 65%.[83]

For now, aortic centers can be expected to continue to adopt patient-by-patient cET and FET approaches according to the abilities and preferences of the surgeon, and the demographics of the patients. In the interim, where cET is employed, it would be valuable if papers outlined rationale and criteria for using cET over FET in particular patient groups. For instance, Inoue et al[52] specify that cET is preferred over FET in ATAAD patients who (1) either have or are strongly suspected to have connective tissue disease, based on previous definitive genetic diagnosis or multiple family history; (2) have no severe organ malperfusion below the distal arch; (3) have not had their descending aorta involved in the aortic dissection; (4) have the majority of the 8th to– 12th intercostal and 1st and 2nd lumbar arteries arising from the FL. However, considering all the evidence included, FET offers most versatility as a treatment option.

Conclusion

When the pathology is limited to the proximal descending aorta, such as in ATAAD, FET has similar advantageous operative outcomes to cET but, crucially, does not necessitate a second-stage procedure and is able to better remodel the FL. The major limitation of FET is SCI, which some groups have started to circumvent. Many other aortic diseases do require second-stage intervention, and even in these cases, there appears to be lower in-hospital mortality when using FET over cET. This is possibly due to the higher rate of endovascular completion facilitated by the more ideal landing zones created during FET. Whether cET or FET is preferable for chronic dissection and aneurysmal disease remains at the discretion of the surgeons as two-stage procedures are to be expected in this cohort when using FET. FET is trending toward becoming the universal treatment modality for descending aortic pathology.

Authors' Contribution

A.G., M.J. and M.T. involved in literature review design, literature search, and manuscript writing. M.B., I.M., and S.H. involved in manuscript revision.

Conflict of Interest

None declared.

References

1 Borst HG, Walterbusch G, Schaps D. Extensive aortic replacement using "elephant trunk" prosthesis. Thorac Cardiovasc Surg 1983; 31(01):37–40
2 Borst HG. The birth of the elephant trunk technique. J Thorac Cardiovasc Surg 2013;145(01):44
3 Shrestha M, Martens A, Krüger H, et al. Total aortic arch replacement with the elephant trunk technique: single-centre 30-year results. Eur J Cardiothorac Surg 2014;45(02):289–295, discussion 295–296
4 Shrestha M, Beckmann E, Krueger H, et al. The elephant trunk is freezing: the Hannover experience. J Thorac Cardiovasc Surg 2015;149(05):1286–1293
5 Di Eusanio M, Pantaleo A, Murana G, et al. Frozen elephant trunk surgery—the Bologna's experience. Ann Cardiothorac Surg 2013;2 (05):597–605
6 Kato M, Ohnishi K, Kaneko M, et al. Development of an expandable intra-aortic prosthesis for experimental aortic dissection. ASAIO J 1993;39(03):M758–M761
7 Kato M, Ohnishi K, Kaneko M, et al. New graft-implanting method for thoracic aortic aneurysm or dissection with a stented graft. Circulation 1996;94(09):II188–II193
8 Castrovinci S, Murana G, de Maat GE, et al. The classic elephant trunk technique for staged thoracic and thoracoabdominal aortic repair: long-term results. J Thorac Cardiovasc Surg 2015;149(02): 416–422
9 Karck M, Chavan A, Hagl C, Friedrich H, Galanski M, Haverich A. The frozen elephant trunk technique: a new treatment for thoracic aortic aneurysms. J Thorac Cardiovasc Surg 2003;125(06):1550–1553
10 Hanif H, Dubois L, Ouzounian M, et al; Canadian Thoracic Aortic Collaborative (CTAC) Investigators. Aortic arch reconstructive surgery with conventional techniques vs frozen elephant trunk: a systematic review and meta-analysis. Can J Cardiol 2018;34(03): 262–273
11 Bozso SJ, White A, Nagendran J, Moon MC, Chu MWA. Hybrid aortic arch and frozen elephant trunk reconstruction: bridging the gap between conventional and total endovascular arch repair. Expert Rev Cardiovasc Ther 2018;16(03):209–217
12 Kreibich M, Berger T, Rylski B, et al. Aortic reinterventions after the frozen elephant trunk procedure. J Thorac Cardiovasc Surg 2020;159(02):392–399.e1

13 Tsagakis K, Pacini D, Di Bartolomeo R, et al. Multicenter early experience with extended aortic repair in acute aortic dissection: is simultaneous descending stent grafting justified? J Thorac Cardiovasc Surg 2010;140(06):S116–S120, discussion S142–S146
14 Jakob H, Tsagakis K, Pacini D, et al. The International E-vita Open Registry: data sets of 274 patients. J Cardiovasc Surg (Torino) 2011;52(05):717–723
15 Jakob H, Tsagakis K. DeBakey type I dissection: when hybrid stent-grafting is indicated? J Cardiovasc Surg (Torino) 2010;51(05): 633–640
16 Jakob H, Dohle D, Benedik J, et al. Long-term experience with the E-vita Open hybrid graft in complex thoracic aortic disease†. Eur J Cardiothorac Surg 2017;51(02):329–338
17 Shrestha M, Kaufeld T, Beckmann E, et al. Total aortic arch replacement with a novel 4-branched frozen elephant trunk prosthesis: Single-center results of the first 100 patients. J Thorac Cardiovasc Surg 2016;152(01):148–159.e1
18 Berger T, Weiss G, Voetsch A, et al. Multicentre experience with two frozen elephant trunk prostheses in the treatment of acute aortic dissection†. Eur J Cardiothorac Surg 2019;56(03):572–578
19 Safi HJ, Miller CC III, Estrera AL, et al. Optimization of aortic arch replacement: two-stage approach. Ann Thorac Surg 2007;83(02): S815–S818, discussion S824–S831
20 Shrestha M, Bachet J, Bavaria J, et al. Current status and recommendations for use of the frozen elephant trunk technique: a position paper by the Vascular Domain of EACTS. Eur J Cardiothorac Surg 2015;47(05):759–769
21 Palma JH, Almeida DR, Carvalho AC, Andrade JC, Buffolo E. Surgical treatment of acute type B aortic dissection using an endoprosthesis (elephant trunk). Ann Thorac Surg 1997;63(04):1081–1084
22 Etz CD, Plestis KA, Kari FA, et al. Staged repair of thoracic and thoracoabdominal aortic aneurysms using the elephant trunk technique: a consecutive series of 215 first stage and 120 complete repairs. Eur J Cardiothorac Surg 2008;34(03):605–614, discussion 614–615
23 Tan SZCP, Lopuszko A, Munir W, Adams B, Bashir M. Aortic proximalization-Zone 0 versus Zone 2: a concept or true challenge? J Card Surg 2021;36(09):3319–3325
24 Di Bartolomeo R, Murana G, Di Marco L, et al. Frozen versus conventional elephant trunk technique: application in clinical practice. Eur J Cardiothorac Surg 2017;51(Suppl 1):i20–i28
25 Leontyev S, Tsagakis K, Pacini D, et al. Impact of clinical factors and surgical techniques on early outcome of patients treated with frozen elephant trunk technique by using EVITA open stent-graft: results of a multicentre study. Eur J Cardiothorac Surg 2016;49(02):660–666
26 Leone A, Di Marco L, Coppola G, et al. Open distal anastomosis in the frozen elephant trunk technique: initial experiences and preliminary results of arch zone 2 versus arch zone 3†. Eur J Cardiothorac Surg 2019;56(03):564–571
27 Chauvette V, Ouzounian M, Chung J, et al; Canadian Thoracic Aortic Collaborative. Review of frozen elephant trunk repair with the Thoraflex Hybrid device. Future Cardiol 2021;17(07):1171–1181
28 Tan SZCP, Bashir M. Prevention versus cure: is BioGlue priming the optimal strategy against E-Vita NEO graft oozing? J Card Surg 2022;37(03):555–560
29 Di Bartolomeo R, Murana G, Di Marco L, et al. Is the frozen elephant trunk frozen? Gen Thorac Cardiovasc Surg 2019;67(01):111–117
30 Preventza O, Liao JL, Olive JK, et al. Neurologic complications after the frozen elephant trunk procedure: A meta-analysis of more than 3000 patients. J Thorac Cardiovasc Surg 2020;160(01):20–33.e4
31 Vernice NA, Wingo ME, Walker PB, et al. The great vessel freeze-out: a meta-analysis of conventional versus frozen elephant trunks in aortic arch surgery. J Card Surg 2022;37(08):2397–2407
32 Poon SS, Tian DH, Yan T, et al; International Aortic Arch Surgery Study Group. Frozen elephant trunk does not increase incidence of paraplegia in patients with acute type A aortic dissection. J Thorac Cardiovasc Surg 2020;159(04):1189–1196.e1
33 Mehanna M, Elhamami M, Abolkasem A, Ramadan B, Almaghraby A, Mascaro J. Aortic remodelling and false lumen changes after the frozen elephant trunk technique using the thoraflex hybrid stented graft for aortic dissection. Egypt Heart J 2021;73(01):74
34 Usai MV, Ibrahim A, Oberhuber A, et al. Quantification of volume changes in the descending aorta after frozen elephant trunk procedure using the Thoraflex hybrid prosthesis for type A aortic dissection. J Thorac Dis 2021;13(01):60–66
35 Liu H, Liu S, Zaki A, et al. Quantifying the learning curve of emergent total arch replacement in acute type A aortic dissection. J Thorac Dis 2020;12(08):4070–4081
36 Liu K, Zhu C, Zheng X, et al. A New Aortic Arch Inclusion Technique With Frozen Elephant Trunk for Type A Aortic Dissection. Ann Surg 2020;271(05):978–983
37 Furutachi A, Takamatsu M, Nogami E, et al. Early and mid-term outcomes of total arch replacement with the frozen elephant trunk technique for type A acute aortic dissection. Interact Cardiovasc Thorac Surg 2019;29(05):753–760
38 Roselli EE, Idrees JJ, Bakaeen FG, et al. Evolution of simplified frozen elephant trunk repair for acute DeBakey type i dissection: midterm outcomes. Ann Thorac Surg 2018;105(03):749–755
39 Shrestha M, Martens A, Kaufeld T, et al. Single-centre experience with the frozen elephant trunk technique in 251 patients over 15 years. Eur J Cardiothorac Surg 2017;52(05):858–866
40 Dohle D-S, Tsagakis K, Janosi RA, et al. Aortic remodelling in aortic dissection after frozen elephant trunk†. Eur J Cardiothorac Surg 2016;49(01):111–117
41 Takagi H, Umemoto TALICE Group. A meta-analysis of total arch replacement with frozen elephant trunk in acute type a aortic dissection. Vasc Endovascular Surg 2016;50(01):33–46
42 Zhang K, Pan XD, Dong SB, et al. Cardiopulmonary bypass duration is an independent predictor of adverse outcome in surgical repair for acute type A aortic dissection. J Int Med Res 2020;48(11): 300060520968450
43 Di Marco L, Leone A, Murana G, et al. Acute type A aortic dissection: Rationale and outcomes of extensive repair of the arch and distal aorta. Int J Cardiol 2018;267:145–149
44 Di Eusanio M, Castrovinci S, Tian DH, et al. Antegrade stenting of the descending thoracic aorta during DeBakey type 1 acute aortic dissection repair. Eur J Cardiothorac Surg 2014;45(06): 967–975
45 Ius F, Fleissner F, Pichlmaier M, et al. Total aortic arch replacement with the frozen elephant trunk technique: 10-year follow-up single-centre experience. Eur J Cardiothorac Surg 2013;44(05): 949–957
46 Sun L, Qi R, Zhu J, Liu Y, Zheng J. Total arch replacement combined with stented elephant trunk implantation: a new “standard” therapy for type a dissection involving repair of the aortic arch? Circulation 2011;123(09):971–978
47 Jakob H, Dohle DS, Piotrowski J, et al. Six-year experience with a hybrid stent graft prosthesis for extensive thoracic aortic disease: an interim balance. Eur J Cardiothorac Surg 2012;42(06):1018–1025
48 Uchida N, Katayama A, Tamura K, et al. Long-term results of the frozen elephant trunk technique for extended aortic arch disease. Eur J Cardiothorac Surg 2010;37(06):1338–1345
49 Di Bartolomeo R, Pantaleo A, Berretta P, et al. Frozen elephant trunk surgery in acute aortic dissection. J Thorac Cardiovasc Surg 2015;149(02):S105–S109
50 Iafrancesco M, Goebel N, Mascaro J, et al; International E-vita Open Registry Group. Aortic diameter remodelling after the frozen elephant trunk technique in aortic dissection: results from an international multicentre registry. Eur J Cardiothorac Surg 2017;52(02):310–318
51 Jakob H, Tsagakis K, Tossios P, et al. Combining classic surgery with descending stent grafting for acute DeBakey type I dissection. Ann Thorac Surg 2008;86(01):95–101

52 Inoue Y, Matsuda H, Omura A, et al. Comparative study of the frozen elephant trunk and classical elephant trunk techniques to supplement total arch replacement for acute type A aortic dissection†. Eur J Cardiothorac Surg 2019;56(03):579–586
53 Kaneyuki D, Mogi K, Watanabe H, Otsu M, Sakurai M, Takahara Y. The frozen elephant trunk technique for acute retrograde type A aortic dissection: preliminary results. Interact Cardiovasc Thorac Surg 2020;31(06):813–819
54 Yoshitake A, Tochii M, Tokunaga C, et al. Early and long-term results of total arch replacement with the frozen elephant trunk technique for acute type A aortic dissection. Eur J Cardiothorac Surg 2020;58(04):707–713
55 Matsuzaki Y, Yamasaki T, Hohri Y, Hiramatsu T. Surgical strategies for type B aortic dissection by frozen elephant Trunk. Ann Vasc Dis 2019;12(04):473–479
56 Weiss G, Tsagakis K, Jakob H, et al. The frozen elephant trunk technique for the treatment of complicated type B aortic dissection with involvement of the aortic arch: multicentre early experience. Eur J Cardiothorac Surg 2015;47(01):106–114, discussion 114
57 Subramanian S, Roselli EE. Thoracic aortic dissection: long-term results of endovascular and open repair. Semin Vasc Surg 2009;22(02):61–68
58 Fattori R, Bacchi-Reggiani L, Bertaccini P, et al. Evolution of aortic dissection after surgical repair. Am J Cardiol 2000;86(08):868–872
59 Immer FF, Krähenbühl E, Hagen U, et al. Large area of the false lumen favors secondary dilatation of the aorta after acute type A aortic dissection. Circulation 2005;112(09):I249–I252
60 Rylski B, Milewski RK, Bavaria JE, et al. Outcomes of surgery for chronic type A aortic dissection. Ann Thorac Surg 2015;99(01):88–93
61 Luo C, Qi R, Zhong Y, et al. Early and long-term follow-up for chronic type B and type non-A non-B aortic dissection using the frozen elephant trunk technique. Front Cardiovasc Med 2021;8:714638
62 Beckmann E, Martens A, Korte W, et al. Open total arch replacement with trifurcated graft and frozen elephant trunk. Ann Cardiothorac Surg 2020;9(03):170–177
63 Kreibich M, Siepe M, Berger T, et al. The frozen elephant trunk technique for the treatment of type B and type non-A non-B aortic dissection. Eur J Vasc Endovasc Surg 2021;61(01):107–113
64 Chen Y, Ma WG, Li JR, et al. Is the frozen elephant trunk technique justified for chronic type A aortic dissection in Marfan syndrome? Ann Cardiothorac Surg 2020;9(03):197–208
65 Charchyan E, Breshenkov D, Belov Y. Follow-up outcomes after the frozen elephant trunk technique in chronic type B dissection. Eur J Cardiothorac Surg 2020;57(05):904–911
66 Yamane Y, Katayama K, Furukawa T, et al. Mid-term results of frozen elephant trunk technique for chronic aortic dissection. Ann Vasc Dis 2020;13(02):137–143
67 Berger T, Kreibich M, Morlock J, et al. True-lumen and false-lumen diameter changes in the downstream aorta after frozen elephant trunk implantation. Eur J Cardiothorac Surg 2018;54(02):375–381
68 Coselli JS, LeMaire SA, Carter SA, Conklin LD. The reversed elephant trunk technique used for treatment of complex aneurysms of the entire thoracic aorta. Ann Thorac Surg 2005;80(06):2166–2172, discussion 2172
69 Ando M, Takamoto S, Okita Y, Morota T, Matsukawa R, Kitamura S. Elephant trunk procedure for surgical treatment of aortic dissection. Ann Thorac Surg 1998;66(01):82–87
70 Schepens MA, Dossche KM, Morshuis WJ, van den Barselaar PJ, Heijmen RH, Vermeulen FE. The elephant trunk technique: operative results in 100 consecutive patients. Eur J Cardiothorac Surg 2002;21(02):276–281
71 Svensson LG, Kim KH, Blackstone EH, et al. Elephant trunk procedure: newer indications and uses. Ann Thorac Surg 2004;78(01):109–116
72 LeMaire SA, Carter SA, Coselli JS. The elephant trunk technique for staged repair of complex aneurysms of the entire thoracic aorta. Ann Thorac Surg 2006;81(05):1561–1569, discussion 1569
73 Aftab M, Idrees JJ, Cikach F, Navia JL, Hammer D, Roselli EE. Open distal fenestration of chronic dissection facilitates endovascular elephant trunk completion: late outcomes. Ann Thorac Surg 2017;104(06):1960–1967
74 Roselli EE, Bakaeen FG, Johnston DR, Soltesz EG, Tong MZ. Role of the frozen elephant trunk procedure for chronic aortic dissection. Eur J Cardiothorac Surg 2017;51(Suppl 1):i35–i39
75 Roselli EE, Sepulveda E, Pujara AC, Idrees J, Nowicki E. Distal landing zone open fenestration facilitates endovascular elephant trunk completion and false lumen thrombosis. Ann Thorac Surg 2011;92(06):2078–2084
76 Kim JB, Sundt TM III. Best surgical option for arch extension of type B aortic dissection: the open approach. Ann Cardiothorac Surg 2014;3(04):406–412
77 Sun L, Zhao X, Chang Q, et al. Repair of chronic type B dissection with aortic arch involvement using a stented elephant trunk procedure. Ann Thorac Surg 2010;90(01):95–100
78 Pacini D, Tsagakis K, Jakob H, et al. The frozen elephant trunk for the treatment of chronic dissection of the thoracic aorta: a multicenter experience. Ann Thorac Surg 2011;92(05):1663-–1670, discussion 1670
79 Di Eusanio M, Armaro A, Di Marco L, et al. Short- and midterm results after hybrid treatment of chronic aortic dissection with the frozen elephant trunk technique. Eur J Cardiothorac Surg 2011;40(04):875–880
80 Rustum S, Beckmann E, Wilhelmi M, et al. Is the frozen elephant trunk procedure superior to the conventional elephant trunk procedure for completion of the second stage? Eur J Cardiothorac Surg 2017;52(04):725–732
81 Weiss G, Santer D, Dumfarth J, et al. Evaluation of the downstream aorta after frozen elephant trunk repair for aortic dissections in terms of diameter and false lumen status. Eur J Cardiothorac Surg 2016;49(01):118–124
82 Fattouch K, Sampognaro R, Navarra E, et al. Long-term results after repair of type a acute aortic dissection according to false lumen patency. Ann Thorac Surg 2009;88(04):1244–1250
83 Chen Y, Ma W-G, Zhi A-H, et al. Fate of distal aorta after frozen elephant trunk and total arch replacement for type A aortic dissection in Marfan syndrome. J Thorac Cardiovasc Surg 2019;157(03):835–849
84 Idrees JJ, Roselli EE, Wojnarski CM, et al. Prophylactic stage 1 elephant trunk for moderately dilated descending aorta in patients with predominantly proximal disease. J Thorac Cardiovasc Surg 2015;150(05):1150–1155
85 Rezaei Y, Bashir M, Mousavizadeh M, et al. Frozen elephant trunk in total arch replacement: A systematic review and meta-analysis of outcomes and aortic proximalization. J Card Surg 2021;36(06):1922–1934
86 Yamamoto H, Kadohama T, Yamaura G, et al. Total arch repair with frozen elephant trunk using the "zone 0 arch repair" strategy for type A acute aortic dissection. J Thorac Cardiovasc Surg 2019:S0022-5223(19)30360-5
87 Tsagakis K, Wendt D, Dimitriou AM, et al. The frozen elephant trunk treatment is the operation of choice for all kinds of arch disease. J Cardiovasc Surg (Torino) 2018;59(04):540–546
88 Gkremoutis A, Zierer A, Schmitz-Rixen T, et al. Staged treatment of mega aortic syndrome using the frozen elephant trunk and hybrid thoracoabdominal repair. J Thorac Cardiovasc Surg 2017;154(06):1842–1849
89 Folkmann S, Weiss G, Pisarik H, Czerny M, Grabenwoger M. Thoracoabdominal aortic aneurysm repair after frozen elephant trunk procedure. Eur J Cardiothorac Surg 2015;47(01):115–119, discussion 119
90 Svensson LG, Kouchoukos NT, Miller DC, et al; Society of Thoracic Surgeons Endovascular Surgery Task Force. Expert consensus

document on the treatment of descending thoracic aortic disease using endovascular stent-grafts. Ann Thorac Surg 2008;85(01): S1–S41
91 Chen SW, Zhong YL, Ge YP, et al. Successful repair of acute type A aortic dissection during pregnancy at 16th gestational week with maternal and fetal survival: A case report and review of the literature. World J Clin Cases 2019;7(18): 2843–2850
92 Tian DH, Wan B, Di Eusanio M, Black D, Yan TD. A systematic review and meta-analysis on the safety and efficacy of the frozen elephant trunk technique in aortic arch surgery. Ann Cardiothorac Surg 2013;2(05):581–591

