Editorial

Frozen elephant trunk: the gold standard

Type A aortic dissection (TAAD) is a life-threatening emergency requiring imperative diagnosis and prompt surgical treatment. The primary aim of open surgical repair (OSR) in TAAD is resecting the origin of the intimal tear located in the ascending aorta. Importantly, this may extend to involve the arch and proximal descending thoracic aorta (DTA), hence necessitating partial or complete replacement of the aortic arch with possible ante-/retro-grade stenting of the DTA (1). Borst *et al.* (2) were the first to describe the elephant trunk (ET) procedure which involves replacing varying portions of the ascending aorta and the arch with a separate free-floating stent extension inserted into the DTA. The latter is performed as a second-stage procedure with retrograde endovascular access to facilitate fixation of the trunk and elimination of the false lumen (FL) distally (2).

The frozen elephant trunk (FET), pioneered in 1996, merges the two stages of the conventional ET (CET) procedure into a single-stage hybrid total arch replacement (TAR). This procedure circumvents the cumulative hazards with the two-staged surgery as well as the interval mortality associated with CET. FET follows the same principles as CET in terms of ascending aorta and proximal arch replacement using a Dacron arch prosthesis. However, it utilises antegrade placement of a self-expandable stent-graft into the DTA in a single-step hybrid fashion. This 'freezing' of the trunk facilitates the re-establishment of true lumen (TL), with improved FL thrombosis and subsequent aortic remodelling, leading to more optimal clinical outcomes (3,4). The favourable hybrid profile that FET offers has resulted in a major rise in commercial interest with the development of several FET hybrid prostheses of varying designs and features.

As aforementioned, the introduction of FET revolutionised the field of aortic surgery by outperforming the CET techniques in TAR, particularly regarding survival, as mortality rates in the literature have been ascertained to favour FET over CET. A contemporary meta-analysis demonstrated lower perioperative mortality (RR: 0.50, 95% CI: 0.42, 0.60; P<0.001) and improved 1-year survival (HR: 0.63, 95% CI: 0.42. 0.95; P=0.03) with FET (5).

Still, FET is associated with a non-negligible risk of postoperative complications including endoleak, distal stent-graft induced new entry (dSINE) and spinal cord ischaemia (SCI) amongst other less common events, all of which may require secondary intervention, negating its single-stage advantage. A meta-analysis incorporating four different FET devices and results from 43 studies showed a 7% (95% CI: 5–12%) rate of secondary endovascular reintervention following FET repair. It also demonstrated a 2% pooled rate of dSINE (95% CI: 1–6%), a 6% pooled rate of postoperative cerebrovascular events (95% CI: 4–10%), and an 11% pooled rate of postoperative renal failure (95% CI: 7–16%) following FET repair. However, the results had a high rate of heterogeneity which was explained by the different types of stent-graft used as well as the various study geographical locations (6).

Spinal cord ischaemia is considered to be a major drawback of the FET procedure. Two earlier meta-analyses have shown a pooled SCI incidence of 4.7–5.1%, and a 4.9–7.6% rate for postoperative stroke post-FET (7,8). The recent meta-analysis of 5,068 patients by Nakhaei *et al.* (6) reported a 3% incidence of SCI following FET (95% CI: 2–4%). The position of the stent-graft below the T8 vertebra or of length ≥15 cm and postoperative hypotension (<70 mmHg) have been identified as independent and modifiable risk factors for SCI in FET (7,9). The incidence of SCI where the stent length is ≥15 cm or the coverage extends to T8 or beyond was significantly higher when compared to a stent length of 10 cm (11.6% *vs.* 2.5%, P<0.001) (7). Retaining the stent-graft above T9 and maintaining an average post-operative systolic blood pressure >90 mmHg were described as prophylactic measures to reduce SCI risk when performing FET (10). Therefore, succeeding practices tended to avoid both longer FET stent-grafts and extended distal aortic coverage. Such improvements were reflected in the contemporary results of a recent meta-analysis highlighting no significant difference in the incidences of postoperative stroke and SCI between FET and CET (5).

Longer FET stent-grafts, although increase the risk of SCI, promote more favourable aortic remodelling. Aortic remodelling is well-established in the literature as a significant prognostic factor following TAR, with FET exhibiting excellent aortic remodelling, including optimal FL thrombosis rates and significant positive changes in TL and FL diameters (11). For example, in a meta-analysis of 1,279 FET patients, FL thrombosis was achieved in 96.8% of patients (95% CI: 90.7–98.9%) (12). Similarly, these findings were supported in a review by Di Bartolomeo *et al.* (13), where complete or partial FL thrombosis was seen in 90% of patients. In addition, the published literature has shown similar remodelling trends in both acute and chronic dissections. More specifically, this excellent remodelling post-FET is more significant level of graft and bronchial carina, in addition to the DTA. Unfortunately, these promising results have not been exhibited to the same extent distally at the level of the abdominal aorta (11). The aforementioned Nakhaei *et al.* (6) meta-analysis showed that the rate of FL thrombosis was 91% around the stent-graft, 61% at the DTA level and 36% at the level of the abdominal aorta.

Notably, the aortic zone of FET HP distal anastomosis represents a hot topic for debate amongst aortic surgeons. Over the past decade, the distal anastomosis zone has shifted from aortic zone 3 (Z-3-FET) to zone 2 (Z-2-FET). Besides being less technically demanding, Z-2-FET had improved clinical outcomes showing lower SCI, visceral ischemia, and cardiovascular complications when compared to Z-3-FET (14,15). However, due to extended distal coverage of the DTA by the stent-graft in Z-3-FET, it is associated with improved aortic remodelling. A meta-analysis comparing Z-2-FET and Z-3-FET showed an overall improvement in results with the prior, with a significantly lower rate of postoperative renal failure (14). Further, recent reports encourage proximalization to zone 0, as it appears to have a more accessible surgical approach as well as shorter cardiopulmonary bypass than Z-2-FET, both of which facilitate a more optimal postoperative profile. However, further evidence is needed from larger comparative studies to reach a definitive conclusion (16).

When all fails, secondary intervention following FET for any of the above mentioned causes is warranted, which can be performed with OSR or endovascularly. The majority of reintervention cases are due to dSINE, negative aortic remodelling or endoleak, with rates ranging from 0–12.9%, 1.6–29.9% and 0–4.55%, respectively, within the published literature. In rarer cases, reintervention can also include graft kinking and aorto-oesophageal fistulae. Interestingly, the choice of FET device as well as its size and length can help minimise the risk of reintervention (17,18).

There are several commercially available FET devices including Thoraflex Hybrid (Terumo Aortic, Inchinnan, Scotland, UK), E-vita Open (JOTEC GmbH, Hechingen, Germany), Cronus (MicroPort, china), and Frozenix J Graft (Japan Lifeline, Tokyo, Japan) (19). Cumulative experience is generally more documented for both Thoraflex Hybrid Plexus (THP) and E-vita Open. In contrast to E-vita Open, THP has a quadrifurcated proximal vascular portion to facilitate the reconstruction of the epi-aortic vessels. Such design represents a key advantage over other commercially available devices, given its ability to address dissected supra-aortic vessels. Thoraflex Hybrid received FDA approval for commercial use in the United States earlier in 2022 and can be considered the primary graft choice (19,20). The prospects of custom-made FET are looking increasingly promising for the future of TAR. Chivasso *et al.* (21) recently published their experience modifying THP into a custom-made FET device which allows full and continuous cerebral perfusion during the circulatory arrest time of FET procedures in addition to facilitating direct end-to-end anastomosis of the supra-aortic vessels more proximally on the arch.

A meta-analysis comprising 1,919 E-vita and 242 THP patients who underwent repair for thoracic aortic aneurysms showed a higher rate of 30-day (3.3% *vs.* 6.99%) and one-year mortality (21.2% *vs.* 17%) for THP patients. However, the authors noted a significantly higher proportion of acute cases utilising THP (22). Subsequent reports, likely due to increased operative experience, demonstrated outstanding success of FET with the THP in treating patients with proximal aortic pathologies. The largest multicentre study on THP comprising 931 patients treated for various aortic pathologies showed a 0.6% 30-day mortality rate and 1.5% overall mortality at 84 months follow-up post-THP implantation. Furthermore, the authors showed a 99% survival rate and 95% freedom from adverse events at the study endpoint (23). In addition, Wisniewski and colleagues reported an 8.6% in-hospital mortality rate in patients with TAAD receiving THP. Interestingly, patients had a mid-term survival of 97% at 26 months after discharge. These results are highly favourable given the urgent and complex nature of the pathology (24).

Given the well-proven superiority of FET over CET, what is the fate of the latter in this current hybrid era? Despite the applicability of the FET procedure in most thoracic aortic pathologies of varying complexity, yet, some patients may benefit more from CET repair. For example, in patients with descending aortic free rupture, severe isthmus stenosis, or mycotic aneurysms, CET remains a more reasonable approach than FET due to the unsuitability of the DTA for antegrade stent-graft implantation (25).

The use of FET in treating complex thoracic aortic pathologies implicating the arch and DTA remains the gold-standard despite emerging techniques and novel devices. More recently, the Ascyrus Medical Dissection Stent (AMDS) was introduced to treat TAAD via antegrade placement of a bare stent into the aortic arch as an adjunct to prior hemi-arch replacement in order to seal the intimal tear(s) and induce TL patency. Still, a recent comparative review highlighted that the FET technique remains the best evidenced-based approach to managing TAAD in this era (26).

Acknowledgments

The evidence used to support this editorial are publicly available in electronic databases such as PubMed, Google Scholar, Ovid, Scopus and Embase.
Funding: None.

Footnote

Provenance and Peer Review: This article was commissioned by the editorial office, *Cardiovascular Diagnosis and Therapy* for the series “Frozen Elephant Trunk”. The article did not undergo external peer review.

Conflicts of Interest: All authors have completed the ICMJE uniform disclosure form (available at https://cdt.amegroups.com/article/view/10.21037/cdt-23-144/coif). The series “Frozen Elephant Trunk” was commissioned by the editorial office without any funding or sponsorship. MB, MI and EPC served as the unpaid Guest Editors of the series. The authors have no other conflicts of interest to declare.

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

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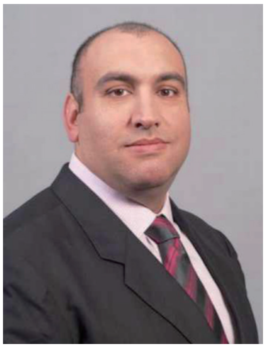
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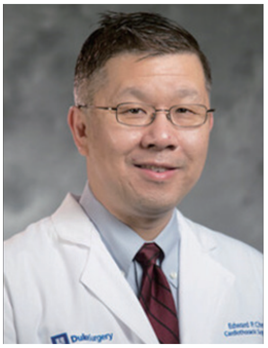
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Keywords: Frozen elephant trunk (FET); total arch replacement (TAR); type A aortic dissection (TAAD)

Submitted Mar 30, 2023. Accepted for publication Apr 13, 2023. Published online Apr 24, 2023.
doi: 10.21037/cdt-23-144
View this article at: https://dx.doi.org/10.21037/cdt-23-144

Cite this article as: Bashir M, Mohammed I, Al-Tawil M, Jubouri M, Agbobu T, Chen EP. Frozen elephant trunk: the gold standard. Cardiovasc Diagn Ther 2023;13(3):623-627. doi: 10.21037/cdt-23-144