Fenestrated-branched endovascular repair for distal thoracoabdominal aortic pathology after total aortic arch replacement with frozen elephant trunk

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ABSTRACT

Objective: To report the outcomes of fenestrated-branched endovascular repair (FBEVAR) for thoracoabdominal aortic pathology after total aortic arch replacement with frozen elephant trunk (TAR+FET).

Methods: Interrogation of prospectively maintained databases from four high-volume aortic centers identified consecutive patients treated with distal FBEVAR after prior TAR+FET between August 2013 and September 2020. The primary end point was 30-day/in-hospital mortality. Secondary end points were technical success, early clinical success, midterm survival, and freedom from reintervention. Data are presented as median (interquartile range).

Results: A total of 39 patients (21 men; median age, 73 years [67-75 years]) with degenerative (n = 22) and postdissection thoracoabdominal aortic aneurysms (n = 17) (median diameter, 71 mm [61-78 mm]) were identified. Distal FBEVAR was intended in 27 patients (median interval, 9.8 months [6.2-16.6 months]), anticipated in 7, and unexpected in 5. A total of 31 patients had a two- (n = 24) or three-stage (n = 7) distal FBEVAR. Renovisceral target vessel preservation was 99.3% (145 of 146). Early primary and secondary technical success was 92% and 97%, respectively. Thirty-day mortality was 2.6% (n = 1; respiratory failure and spinal cord ischemia [SCI]). Six survivors also developed SCI, which was associated with complete (n = 4) or partial recovery (n = 2) at hospital discharge. No patients required renal replacement therapy or suffered a stroke. Early clinical success was 95%. Median follow-up was 30.5 months (23.7-49.7 months). Eleven patients required 16 late reinterventions. Estimated 3-year survival and freedom from reintervention were 84% ± 6% and 63% ± 10%, respectively.

Conclusions: Distal FBEVAR after prior TAR+FET is associated with high technical success and low early mortality. The risk of SCI is significant although the majority of patients demonstrate full or partial recovery before hospital discharge. Midterm patient survival is favorable, but there remains a high requirement for late reintervention. FBEVAR represents an acceptable alternative to distal open thoracoabdominal aortic aneurysm repair. (J Vasc Surg 2022;76:867-74.)

Keywords: Frozen elephant trunk; Fenestrated; Branch; Endovascular; Distal repair

The traditional surgical approach to patients with proximal and distal aortic aneurysmal disease is two-stage repair comprising total arch replacement with a floating elephant trunk followed by open descending thoracic aorta (DTA) or thoracoabdominal aortic aneurysm (TAAA) repair.[1] Both procedures represent a major physiological insult, and a significant proportion of patients do not recover sufficiently to have the second-stage procedure, or die from interval rupture.[2-6] Total aortic arch repair using the frozen elephant trunk technique (TAR+FET) has potential advantages by providing a single-stage repair for patients with pathology affecting the proximal aorta and the distal arch/proximal DTA, as well as a more stable and easily accessible platform for endovascular or open distal reconstruction in patients with TAAA. Up to a quarter of patients will require distal aortic reconstruction within

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10 years after TAR+FET, and this may be (1) intended where the distal aorta has already reached size threshold for repair, (2) anticipated where there is progression of an initially subthreshold distal aortic aneurysm, or (3) unexpected where there is new aortic pathology such as type 1b endoleak, stent-graft-induced new entry tear, aortic rupture of fistula formation.[7,8]

Multiple factors determine the best method of distal aortic repair and include the patient's age and physiology, pathology (connective tissue disease, chronic post-dissection, or degenerative aneurysms), the extent of repair required, anatomical suitability for endovascular repair, and local expertise.[9] Several centers have reported the outcomes of distal aortic repair after TAR+FET using standard thoracic endovascular repair (TEVAR) for DTA pathology and open surgical reconstruction for those with TAAA,[7,10-16] but there are few reports describing complex endovascular repair in patients with distal thoracoabdominal aortic pathology.[17-19]

The aim of the present study was to report the short- and midterm outcomes of distal fenestrated-branched endovascular repair (FBEVAR) in patients with prior TAR+FET in four high-volume aortic centers in Europe and North America.

ARTICLE HIGHLIGHTS

- **Type of Research:** Multicenter retrospective analysis of prospectively maintained institutional databases
- **Key Findings:** Fenestrated-branched endovascular repair of thoracoabdominal aortic aneurysms after total arch repair with frozen elephant trunk in 39 patients resulted in 97% technical success, 2.6% early mortality, 5.3% permanent spinal cord ischemia, and 84% 3-year survival.
- **Take Home Message:** Distal fenestrated-branch endovascular repair after total arch repair with frozen elephant trunk is associated with high technical success, low early mortality, and favorable midterm survival and represents an acceptable alternative to distal open repair.

METHODS

The paper was prepared according to reporting of case series in surgery (PROCESS) guidelines.[20] This was a retrospective, multicenter study using routinely collected data conducted within the clinical audit framework; no additional study-dependent intervention was performed, and patients were not contacted outside their routine clinical care. In the United Kingdom, specific ethical approval was not required, and patient consent was not sought in line with guidance from the UK Health Research Authority and UK Policy Framework for Health and Social Care Research. In the U.S. centers, approval was given by the institutional review boards and patients provided written informed consent for participation in this retrospective study. In Italy, patients were part of two other retrospective studies that received ethics committee approval and were registered with clinical trial.gov (NCT03600077 and NCT03342755).

Study cohort. Prospectively maintained databases were interrogated from four aortic centers (University Hospitals Birmingham, UK; San Raffaele Hospital, Milan, Italy; Mayo Clinic, Rochester, USA; and the University of Texas Health Centre at Houston, McGovern Medical School, Houston, USA). All consecutive patients who underwent distal FBEVAR for extent I/II TAAA[21] after previous TAR+FET between August 2013 and September 2020 were included.

Preoperative assessment, imaging, and procedural planning. Patients underwent computed tomographic angiography (CTA) from arch vessels to femoral bifurcations and assessment of their physiological fitness (biochemical/hematological analysis, echocardiography, and cardiopulmonary exercise testing) with clinical review by a vascular anesthetist. Aneurysm morphology on CTA was assessed with postprocessing evaluations (multiplanar, three-dimensional, centerlumen-line reconstructions) using dedicated software for vessel analysis (Aquarius 3D; TeraRecon) to plan the procedural strategy and determine whether to use customized or off-the-shelf devices based on the individual's anatomy and the preference of the operating surgeon. Staged repair was employed after review of the CTA to determine patency of the vertebral (VA), left subclavian, and internal iliac arteries (IIA), as well as the intercostal and lumbar arteries that would be sacrificed by the repair.

Procedural details, perioperative and postoperative care. Access was achieved by either open exposure or an ultrasound-guided percutaneous approach. The FBEVAR was performed as a single-stage procedure or in two or three stages depending on the institutional preference and based on the individual patient's perceived risk of spinal cord ischemia (SCI) taking into account the patency of the spinal collateral network, the patient's cardiorespiratory physiology, and the interval between TAR+FET and FBEVAR. Different spinal cord protection protocols were employed in the centers.[22-24] No prophylactic cerebrospinal fluid (CSF) drainage or neuromonitoring was used in the 16 patients treated in Birmingham, UK. Prophylactic CSF drains were used in 11 of 14 U.S. patients, and 1 of 9 patients treated in Milan. Neuromonitoring using paraspinal near-infrared spectroscopy and/or motor evoked potentials was employed in all of the U.S. patients. The final stage of the FBEVAR was performed under local anesthesia in seven of nine patients treated in Milan. Patients were enrolled into a postoperative surveillance protocol consisting of clinical

Table I. Comorbidity in 39 patients undergoing distal fenestrated-branched endovascular aortic repair (FBEVAR) after total arch replacement with frozen elephant trunk (TAR+FET)

Variable	No. of patients (%)
ASA grade	
II	12 (30.8)
III	25 (64.1)
IV	2 (5.1)
Hypertension	34 (87.2)
COPD	13 (33.3)
CAD	15 (38.5)
PAD	5 (12.8)
Cerebrovascular disease	6 (15.4)
CKD stage 3A-5	14 (35.9)[a]
Diabetes mellitus	3 (7.7)
Dyslipidemia	20 (51.3)
Connective tissue disease	3 (7.7)[b]
Prior aortic dissection	17 (43.6)
A-5	2
A-8	1
A-9	4
A-10	5
A-11	3
B-1-10	2

ASA, American Society of Anesthesiologists; *CAD*, coronary artery disease; *CKD*, chronic kidney disease (stage 3A-5 = estimated glomerular filtration rate <60 mL/min/1.73 m^2); *COPD*, chronic obstructive pulmonary disease; *PAD*, peripheral arterial disease.
[a]No patients had preoperative eGFR <30 mL/min/1.73 m^2.
[b]Three patients with connective tissue disease were aged 46, 52, and 67 years and comorbidities included hypertension (n = 3), COPD (n = 3), CAD (n = 2), and cerebrovascular disease (n = 1).

assessment and CTA at 1, 6, and 12 months and annually thereafter.

Definitions and data collection. The following data were retrieved: demography, comorbidity, endograft design, duration of surgery, adjunctive procedures, staging approach, early mortality, target vessel loss, major complications, reinterventions, total hospital and critical care length of stay, and patient survival and reinterventions during follow-up. Follow-up ended and data were exported for analysis on May 1, 2021. For UK patients, survival status was verified by cross-referencing the local electronic patient record with the NHS-wide mortality database (Primary Care Mortality Database, Spine, NHS Digital) derived from death records from the Office for National Statistics. All Italian and American patients or their families were contacted directly by the responsible team. Patients who lived far from the treating center could be followed up by the referring center, and information was shared on late complications and/or reinterventions. Chronic aortic dissections were classified using the Society for Vascular Surgery (SVS)/Society of Thoracic Surgeons reporting standards.[25] The distal extent of endograft coverage was defined using the SVS classification.[26] Outcome measures were defined according to the SVS reporting standards[27] and comprised early (within 30 days) primary and secondary technical success, early clinical success, overall survival, and freedom from reintervention.

Statistical analysis. This was performed using R environment (version 4.0.3; the R Foundation for Statistical Computing; https://www.r-project.org). Continuous variables were presented as median (interquartile range), and categorical data were presented as proportions. Median follow-up was reported as the observed follow-up in all subjects (irrespective of outcome). Overall survival and freedom from reintervention were assessed by calculating the Kaplan-Meyer product limit estimator with right censoring of survival data.

RESULTS

Patient characteristics. A total of 39 patients (21 men; median age, 73 years [67-75 years]) with degenerative (n = 22) and chronic postdissection TAAA (n = 17) (median diameter, 71 mm [61-78 mm]) were identified. Three patients had connective tissue disease (CTD). All patients had patent bilateral VAs, 37 had patent bilateral IIAs, and 2 had a unilateral IIA occlusion. Comorbidity data are shown in Table I.

Total arch repair with frozen elephant trunk. Before TAR+FET, 15 patients had proximal aortic surgery for acute type A aortic dissection (n = 14) and ascending aortic aneurysm (n = 1). TAR+FET had been performed electively in 33 patients and urgently in 6. In European centers, commercially available devices were used: the E-Vita Open (Plus) (Jotec GmbH) (n = 17) and the Thoraflex (Terumo Aortic) (n = 8). The supra-aortic vessels were revascularized using a combination of inclusion patches and bypass grafts. The stent-graft component of the commercially available prosthesis was 100 mm (n = 1), 130 mm (n = 4), 150 mm (n = 8), 160 mm (n = 8), and 200 mm (n = 4) in length, and the anastomosis between the proximal cuff of the FET and the native aorta was in zone 0 (n = 4), 2 (n = 9), or 3 (n = 12).

In the U.S. centers, where manufactured devices were not approved for clinical use, TAR+FET was performed by combining open prosthetic total arch repair (with separate branches to the supra-aortic vessels) and antegrade deployment of commercially available thoracic endografts 100-150 mm in length all of which sealed proximally in zone 2 where they were sutured in a circular fashion to the open prosthetic graft.[18] These procedures were not performed in a hybrid operating theatre.

Fenestrated-branched endovascular repair. In 27 patients, distal FBEVAR was intended at the time of the decision to perform TAR+FET, and the median interval

between procedures was 9.8 months (6.2-16.6 months). Distal repair was anticipated in seven patients with subthreshold TAAA (diameter less than 60 mm) and unexpected in five patients where the FET had initially sealed distally in the DTA. The median interval between TAR+FET and FBEVAR for the entire cohort was 17.3 months (10.3-34.8 months). In patients with CTD, distal open repair was intended but the approach changed due to a significant decline in respiratory function (n = 2) and patient preference (n = 1) after TAR+FET; the interval in these patients was 19, 22, and 148 months.

Thirty-seven patients were treated with commercially available customized devices (Cook Medical), one patient was treated with a commercially available off-the-shelf BEVAR (T-Branch; Cook Medical), and one with surgeon-modified FEVAR for a symptomatic 11.4-cm-diameter extent II TAAA.[28] All patients successfully completed the distal FBEVAR. The distal endograft seal was in zones 9 (n = 21), 10 (n = 15), and 11 (n = 3). Thirty-one patients had a staged distal repair that was performed during the same admission in three patients: two-stage (n = 24; TEVAR followed by FBEVAR) and three-stage (n = 7; TEVAR followed by FBEVAR; then iliac limb deployment). The median interval between two stages was 103 days (47-144 days) with a further 31 days (28-56 days) for those treated with a third stage. The three patients who had two-stage distal FBEVAR during the same admission (interval 3, 7, and 14 days) had large TAAA (114, 74, and 70 mm diameter) with patent bilateral VAs and IIAs and distal seal in zone 9.

Percutaneous access was used in 51 of 78 common femoral arteries. Adjuvant procedures were required in 20 patients: upper extremity access (n = 19; right: 10, left: 9), iliac stenting (n = 2), and iliofemoral surgical conduit (n = 3). One patient with a complex postdissection TAAA had a planned left external iliac artery to renal artery (RA) bypass graft with great saphenous vein before FEVAR. Of the remaining 145 renovisceral vessels, 116 (16 CA, 26 SMA, 74 RA) were targeted for preservation with fenestrations and 29 (13 CA, 12 SMA, 4 RA) with directional branches. A total of 141 vessels (29 CA, 38 SMA, 68 RA) were secured with stent grafts. Six patients had seven iliac branch endografts.

The four target vessels that were not stent-grafted included: one patient with bilateral small RAs (diameter <4 mm) underwent 4-vessel FEVAR with CA and SMA stent grafts, but the intention was not to secure the RA fenestrations with stent grafts as there was adequate wall contact and aneurysm exclusion; one patient where there was severe misalignment of a left RA fenestration and 18 days later a left external iliac artery to RA bypass with vein was performed with deployment of an Amplatzer II vascular plug (Abbott Vascular) within a stent graft to occlude the fenestration; and one patient where an RA could not be catheterized and occluded intraoperatively with no requirement for a vascular plug as there was wall contact and no endoleak. One patient had a type 1c left RA endoleak that was treated with further endografting on postoperative day 7. Renovisceral target vessel preservation was 99.3% (145 of 146). Early primary and secondary technical success were 92% (36 of 39) and 97% (38 of 39), respectively.

Early outcomes after fenestrated-branch endovascular repair. There was one death (2.6%) within 30 days of repair: a 79-year-old woman with unilateral IIA occlusion who underwent two-stage FBEVAR without prophylactic CSF drainage and developed paraplegia that did not improve with therapeutic CSF drainage and was complicated by hospital-acquired pneumonia and respiratory failure. Eight patients suffered 10 major nonfatal complications: SCI (n = 6), respiratory failure (n = 2), congestive cardiac failure (n = 1), and minor hemorrhagic stroke (n = 1). No patients required renal replacement therapy. There were no perioperative complications in the three patients with CTD.

Of the six survivors who developed SCI, all had patent bilateral IIAs. One patient underwent a single-stage FBEVAR without prophylactic CSF drainage or neuromonitoring, and five had prophylactic CSF drainage (four with near-infrared spectroscopy and/or motor evoked potentials) for single- (n = 1), two- (n = 3), and three-stage (n = 1) distal repairs. The patient who had a single-stage repair with prophylactic CSF drainage and neuromonitoring developed SCI secondary to a spinal hematoma after CSF drain removal and required surgical evacuation, which resulted in complete neurological recovery. On discharge from hospital, four patients had recovered completely with normal neurological function and full ambulation, whereas two had partial recovery and were not ambulatory. None of the three patients who had staged repair during the same admission developed SCI.[22] The early clinical success was 95% (37 of 39): technical failure with RA occlusion (n = 1) and perioperative death (n = 1).

Midterm outcomes after fenestrated-branched endovascular repair. No patients were lost to follow-up. The median follow-up was 30.5 months (23.7-49.7 months). The estimated 3-year survival (± standard error) was 84% ± 6% (Fig 1). Five patients died after hospital discharge and within the first postoperative year: four of these patients had significant comorbidity including hypertension (n = 5), coronary artery disease (n = 3), cardiac failure (n = 2), chronic obstructive pulmonary disease (n = 2), and peripheral arterial disease (n = 2). There were no conversions to open repair. There was one late aortic-related death at 38 months after FBEVAR. The patient presented with chest discomfort and hypertension, and CTA demonstrated a type III endoleak between the thoracic and fenestrated components with no evidence of aortic rupture. Blood pressure management

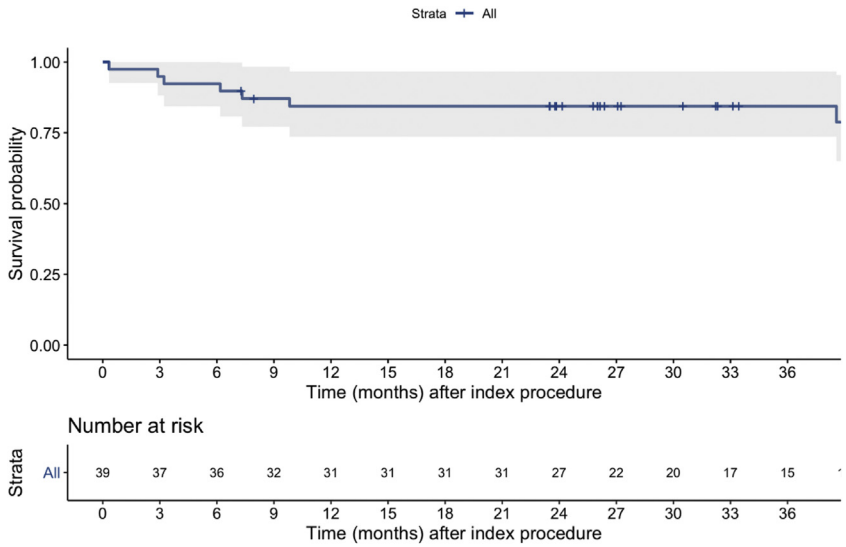

Fig 1. Estimated survival in 39 patients who underwent distal fenestrated-branched endovascular aortic repair (FBEVAR) after total arch replacement with frozen elephant trunk (TAR+FET).

was commenced, and TEVAR was planned for the following morning, but the patient died overnight and postmortem examination confirmed aortic rupture. A review of the follow-up CTA images demonstrated that the overlap between the FET and proximal TEVAR (originally 49 mm) had not changed but the distal TEVAR device had migrated to the outer curve of the aneurysm sac with loss of overlap with the FEVAR (originally 37 mm). Another patient developed the same complication, but this was managed successfully with implantation of a further TEVAR device. Eleven patients required 16 late reinterventions (Table II). One patient with CTD required two late reinterventions. The estimated 3-year freedom from reintervention (± standard error) was 63% ± 10% (Fig 2).

DISCUSSION

The present study demonstrates that distal FBEVAR after total aortic arch replacement with frozen elephant trunk is associated with high technical success and low perioperative mortality. The incidence of SCI was high despite multiple strategies to mitigate this risk, but the majority of patients recovered completely or partially before discharge from hospital. The midterm survival rate (84% at 3 years) was acceptable for a group of elderly patients (median age, 73 years) with relevant comorbidities, and not dissimilar to that achieved in younger patients undergoing distal open TAAA repair in high-volume centers.[2-6] This is likely to reflect a generally higher level of fitness in patients who undergo successful TAR+FET combined with the lower physiological insult of distal endovascular repair. The need for late reintervention was significant and predominantly due to distal disease progression and target vessel stent-graft complications, but these procedures were all achieved using endovascular techniques with no mortality and there were no conversions to open repair.

The patients in the present series were heterogeneous in terms of their pathology (mega-aorta, chronic postdissection, and degenerative TAAA) and were highly selected in that they were fit enough to survive major proximal aortic surgery while being anatomically suitable for distal FBEVAR. The significant physiological insult of TAR+FET is similar to that for TAR with a floating trunk, and the median interval of 10 months between TAR+FET and planned FBEVAR was largely a consequence of the prolonged period of recovery required for these older patients.[7-19] The timing of planned distal FBEVAR was largely based on an objective assessment of the patient's recovery and fitness, while taking into account TAAA diameter and perceived risk of interval rupture as well as allowing sufficient time for adaptation of spinal cord perfusion. The low risk of major adverse events from FBEVAR in the present study would support proceeding with distal repair at an earlier phase of the patient's recovery to reduce the risk of interval rupture.

The principal advantage of frozen elephant trunk is the potential to create a longer, more stable, and relatively kink-resistant proximal seal zone that facilitates planning and implantation of the distal endografts. In two patients, there was inadequate overlap between the TEVAR implanted as the first stage of the distal repair and the subsequent FBEVAR that ultimately led to a type 3 endoleak that was fatal in one of these patients. As a consequence, a minimum overlap of three covered stents between the TEVAR and FBEVAR component is recommended.

The collateral network concept of spinal cord perfusion has had a major impact on spinal cord protection in complex EVAR,[29] and staged endovascular TAAA repair

Table II. Early and late reinterventions in 12 of 39 patients who underwent distal fenestrated-branched endovascular aortic repair (*FBEVAR*) after total arch replacement and frozen elephant trunk (TAR+FET)

Case no.	Aneurysm etiology	Device configuration	Early reintervention	Late reintervention	Outcome
2	Degenerative	3F	EIA-LRA bypass with LSV + occlusion of fenestration (day 18)	39 m: TEVAR for type 3 EL + redo stent-grafting RRA stenosis	Alive
4	Postdissection	4F	–	34 m: limb extension for type 1b EL	Alive
5	Degenerative	4F	–	9 m: angioplasty RRA stent-graft stenosis 32 m: distal body for type 1b EL	Died 40 m
6	Postdissection	4B	–	23 m: redo stent-grafting LRA stenosis 31 m: embolization type 2 EL	Alive
8	Degenerative	2B2F	–	15 m: redo stent-grafting RRA type 3c EL 48 m: TEVAR for type 3 EL TEVAR-FEVAR junction	Alive
12	Degenerative	4F	–	14 m: angioplasty for CA type 1c EL	Died 38 m
13	Postdissection	2B2F	–	24 m: IBD for type 1b EL	Alive
21	Postdissection[a]	4F	–	6 m: embolization type 2 EL 8 m: redo stent-grafting LRA type 1c EL	Alive
23	Postdissection	1B3F	–	14 m: redo stent-grafting LRA type 1c EL	Alive
26	Postdissection	1B3F	Evacuation of spinal hematoma after CSF drain removal	–	Alive
34	Postdissection	4F	Redo LRA stent-grafting for type 1c EL (day 7)	1.5 m: redo stent-grafting CA type 1c/3c EL	Alive
39	Degenerative	4F	–	2 m: coil embolization splenic artery pseudoaneurysm	Alive

B, Branch; *CA*, coeliac axis; *CSF*, cerebrospinal fluid; *EIA*, external iliac artery; *EL*, endoleak; *F*, fenestration; *LRA*, left renal artery; *LSV*, long saphenous vein; *RRA*, right renal artery; *TEVAR*, thoracic endovascular aortic repair; *TV*, target vessel.
[a]Connective tissue disease.

has gained widespread acceptance in high-volume centers. This can be achieved in a number of ways: deploying a standard TEVAR device to just proximal to the coeliac axis, which encourages proximal sac thrombosis and intercostal artery sacrifice; creating temporary aneurysm sac perfusion[30] where a target vessel or specific perfusion branch is unstented or an iliac limb is not implanted; or endovascularly occluding large intercostal and lumbar arteries in multiple stages over a number of weeks or months.[31] In patients with TAAA, the FET will not have aortic wall contact and so the longer devices (150 mm and 160 mm) can be used to encourage some proximal aortic sac thrombosis without a significant increase in the risk of SCI. These longer devices are too short in the majority of patients to encourage sufficient proximal intercostal artery occlusion and minimize the risk of disabling SCI with a single-stage distal FBEVAR, and, therefore, a two- or three-stage distal FBEVAR is recommended.

It is important that the need for proximal access for distal endovascular repair be considered before TAR+FET as the configuration of the reconstructed arch vessels can make this challenging, particularly if the surgical grafts are kinked or tortuous. Although several patients in the present series had arch reconstruction that included a bypass to the left subclavian artery from zone 0, this did preclude distal FBEVAR. Right upper limb access can be considered in such circumstances, but suboptimal proximal access is not a limitation to distal FBEVAR, which can be performed by implanting a fenestrated rather than a branch device with/without the use of adjuvant endovascular techniques to facilitate cannulation of downward facing target vessels such as transfemoral steerable sheaths (Medtronic).

In patients who are unsuitable for distal FBEVAR, open renovisceral artery debranching combined with thoracoabdominal EVAR can deliver early outcomes in high-risk patients that are similar to open TAAA repair in younger lower-risk patients.[17] An alternative approach involves deploying a standard TEVAR device from within the FET to immediately above the coeliac axis, thereby facilitating an open extent IV repair.[8] In selected patients with distal aortic arch pathology and TAAA, a total

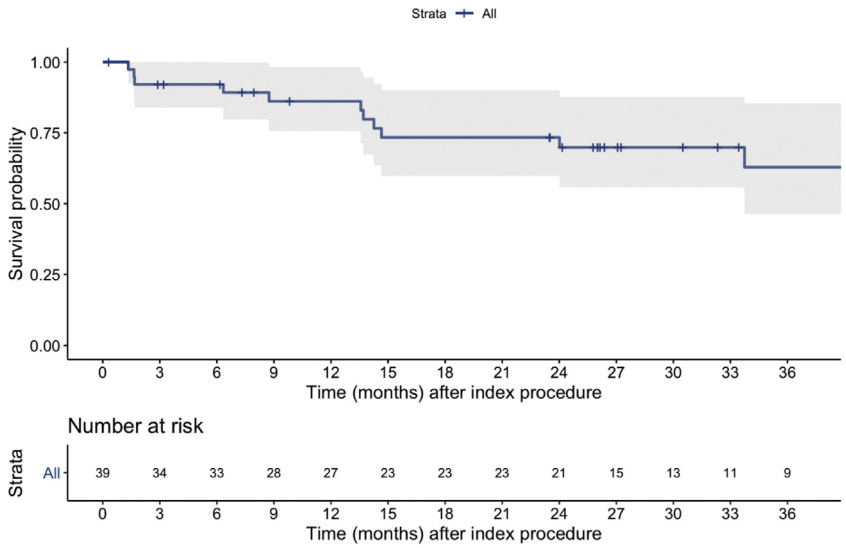

Fig 2. Estimated freedom from reintervention in 39 patients who underwent distal fenestrated-branched endovascular aortic repair (FBEVAR) after total arch replacement with frozen elephant trunk (TAR+FET).

endovascular approach has been shown to deliver favorable perioperative outcomes (6% mortality, 12% SCI) with a 1-year survival rate of 72%,[32] which is comparable to that achieved with the visceral hybrid open-endovascular approach after TAR+FET.[17] The majority of patients who undergo TAR+FET have no suitable proximal landing zone for arch FBEVAR technology.[8] In those patients who are at high risk for TAR+FET, open replacement of the ascending aorta can be performed to create a stable landing zone for a second-stage arch FBEVAR before ultimately proceeding to distal repair.[33]

Study limitations. These include the retrospective nature of the study; the small number of patients and their highly selected nature; the heterogeneity of aortic pathology and the devices used for the frozen elephant trunk procedure; the inability to standardize management protocols, such as spinal cord protection; and the absence of data for a contemporaneous cohort of patients treated with distal open repair.

CONCLUSIONS

In conclusion, distal FBEVAR after open total arch repair with the frozen elephant trunk is associated with high technical success and low perioperative mortality and represents an acceptable alternative to distal open TAAA repair in older and higher-risk patients. Although the risk of SCI is significant even with staged distal repair and adjuvant neuromonitoring, the majority of patients recover before hospital discharge. The midterm survival is favorable but late reinterventions are common. From a technical perspective, it is important to maximize the overlap between the endograft components to prevent late device separation. Distal FBEVAR after prior TAR+FET is an uncommon procedure even in specialist centers, and this underlines the need for centralization of TAAA surgery and further evidence from prospective multicenter registries to define the efficacy of the technique and identify which patients are likely to gain the most from this complex intervention. These studies must include data on patients who fail to proceed to distal aortic repair due to mortality after TAR+FET, poor recovery, and interval mortality from aortic rupture and other causes.

AUTHOR CONTRIBUTIONS

Conception and design: JM, MJ, MC, LB, RC, GO, DA
Analysis and interpretation: AS, ET, LB, GO, DA
Data collection: AS, ET, AM, LB
Writing the article: AS, ET, MJ, MC, LB, GO, DA
Critical revision of the article: ET, JM, MJ, MC, AM, LB, RC, GO, DA
Final approval of the article: AS, ET, JM, MJ, MC, AM, LB, RC, GO, DA
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Overall responsibility: DA

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