



Frozen elephant trunk in normothermia without circulatory arrest: initial experience

Paolo Berretta¹, Simone D'Alessio¹, Pietro G. Malvindi¹, Alessandro D'Alfonso¹, Mariano Cefarelli¹, Michele Galeazzi¹, Olimpia Bifulco¹, Martina Giusti¹, Vincenzo Vento², Francesca Spagnolo¹, Emanuele Gatta², Marco Di Eusanio¹

¹Cardiac Surgery Unit, Lancisi Cardiovascular Center, Polytechnic University of Marche, Ancona, Italy; ²Vascular Surgery Unit, Lancisi Cardiovascular Center, Ancona, Italy

Correspondence to: Paolo Berretta, MD. Cardiac Surgery Unit, Lancisi Cardiovascular Center, Polytechnic University of Marche, Via Conca 71, 60126 Ancona, Italy. Email: p.berretta@icloud.com.

Background: Aortic arch surgery has evolved significantly with novel techniques aimed at reducing morbidity and mortality. Traditional approaches rely on hypothermic circulatory arrest (HCA), which remains associated with neurological and systemic complications. This study presents our initial experience with a normothermic frozen elephant trunk (FET) technique that eliminates circulatory arrest while maintaining continuous cerebral and systemic perfusion.

Methods: A retrospective analysis was conducted on consecutive patients who underwent FET without HCA at Polytechnic University of Marche from September 2019 to January 2025. The surgical strategy included femoral and innominate artery cannulation for extracorporeal circulation, antegrade selective cerebral perfusion (ASCP), and retrograde stent graft deployment with balloon occlusion. Perioperative outcomes, complications, and mid-term follow-up data were evaluated.

Results: Twenty-three patients (median age, 73 years) underwent FET without HCA. Indications included degenerative aneurysm (n=14), type I endoleak (n=4), acute aortic dissection (n=2), chronic penetrating ulcer (n=2), and Kommerell's diverticulum (n=1). Technical success was 100%. Two in-hospital deaths occurred due to septic shock and stroke. No cases of permanent spinal cord injury were reported. The median intensive care unit and hospital stays were 4 and 10 days, respectively. The median peak intraoperative lactate level was 1.8 mmol/L (range, 1–4.8 mmol/L). At a median follow-up of 27 months, three patients required distal aortic reintervention due to type Ib (n=2) and type II (n=1) endoleaks.

Conclusions: Normothermic FET without circulatory arrest is a feasible and potentially advantageous alternative to traditional techniques, reducing ischemia-reperfusion injury while maintaining cerebral and systemic perfusion. Early outcomes suggest promising results in selected patients, though further studies with larger cohorts are necessary to validate long-term safety and efficacy.

Keywords: Frozen elephant trunk (FET); normothermic frozen elephant trunk (normothermic FET); cardiac arrest; FET without circulatory arrest; aortic arch surgery



Submitted Feb 27, 2025. Accepted for publication Jun 30, 2025. Published online Jul 28, 2025.

doi: 10.21037/acs-2025-eket-0042

View this article at: <https://dx.doi.org/10.21037/acs-2025-eket-0042>

Introduction

Aortic arch surgery has significantly evolved over the past decades with the introduction of novel techniques and technologies, expanding treatment options and enhancing operative outcomes. However, traditional surgical approaches

still require hypothermic circulatory arrest (HCA) and prolonged extracorporeal circulation (ECC), which remain major limitations (1). These factors have been strongly associated with increased mortality and morbidity, posing significant challenges to achieving optimal patient

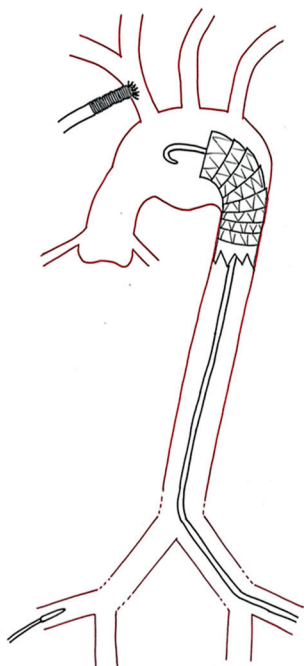


Figure 1 Retrograde zone 2 endograft deployment (off-pump). The right femoral and innominate arteries are cannulated for extracorporeal circulation inflow.

outcomes (1-9). Recently, we introduced a technique that enables the execution of a frozen elephant trunk (FET) under normothermic conditions, eliminating the need for circulatory arrest (10-12). This approach consists of (I) combined femoral and innominate/axillary artery cannulation for ECC arterial return, allowing continuous upper and lower body perfusion; (II) antegrade selective cerebral perfusion (ASCP) with total brain perfusion; (III) retrograde trans-femoral stent graft deployment; and (IV) balloon occlusion following the same route.

Here we present our initial experience in Ancona with this novel approach.

Methods

Study design and patient selection

The present study is a retrospective analysis of outcomes, based on institutional records with prospective data entry. All consecutive patients who underwent FET repair without HCA from September 2019 to January 2025 at the Lancisi Cardiovascular Center in Ancona were included. Patient care was coordinated by a multidisciplinary Aortic Team, involving cardiac surgeons, vascular surgeons and

anesthesiologists, all with extensive experience in both open and catheter-based procedures. Cardiac and vascular surgeons operated in tandem in all cases.

Demographic characteristics, medical history, operative outcomes, mid-term results, and imaging data were systematically collected at the time of admission and during follow-up visits. Data were coded according to the Standards of Reporting in Open and Endovascular Aortic Surgery (STORAGE) guidelines, as well as the current guidelines of the European Association for Cardiothoracic Surgery/European Society of Cardiology and the EuroSCORE II model (13-15). All patients underwent preoperative and early postoperative (<30 days) computed tomography angiography (CTA) and echocardiographic examinations. Follow-up CTA was performed at 3 and/or 6 months, 12 months, and annually thereafter, as needed. More frequent CTA surveillance was scheduled for patients with unfavorable aortic remodeling. Follow-up was completed in 100% of cases. In accordance with local ethical standards, the study was notified to the local ethics committee, and all patients provided written informed consent (approved by the Italian Society for Cardiac Surgery) for the use of their anonymized clinical data for research and publication purposes.

Surgical technique

All procedures were performed in a hybrid operating theatre, with patients under general anesthesia. Bilateral radial arterial line pressure monitoring and near-infrared spectroscopy were employed. Transesophageal echocardiography was routinely used. Cerebrospinal fluid drainage was employed in patients at increased risk of spinal cord injury due to extensive aortic coverage or prior distal aortic procedures. The heart and aorta were accessed via median sternotomy in all cases, and the arch vessels were extensively isolated. Both femoral arteries were surgically exposed. After systemic heparinization, arterial inflow for ECC was established and conducted via the innominate/axillary artery and femoral artery using a Y-connector, ensuring continuous perfusion of both the upper and lower body.

The proximal landing zone of the endograft (zone 1, 2 or 3) was identified and marked using multiple large hemoclips. Through the contralateral femoral artery, guided by an extra-stiff guidewire, an appropriate endograft without a free-flow segment was deployed, aligning its proximal edge with the hemoclip markers (*Figure 1*).

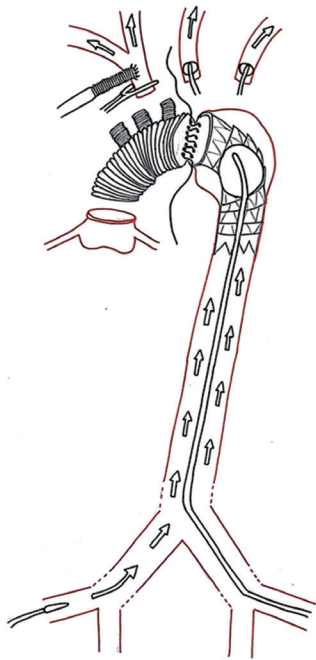


Figure 2 Surgical setup for performing the distal anastomosis without hypothermic circulatory arrest. A combined femoral and innominate artery cannulation for extracorporeal circulation arterial return ensures continuous upper and lower body perfusion, along with antegrade selective cerebral perfusion providing total brain perfusion and retrograde trans-femoral stent graft occlusion using a balloon catheter.

A Reliant balloon (Medtronic, USA) was retrogradely advanced into the stent graft via the same femoral artery using a 14-Fr sheath. Under fluoroscopic guidance, the balloon was inflated to simulate aortic clamping, the inflation volume was recorded, the catheter position was marked, and the balloon was then deflated.

Venous drainage was achieved by cannulation of the right atrium, and the left ventricle was vented via the right superior pulmonary vein. ECC was initiated through innominate/axillary artery inflow. The left subclavian artery (LSA) was ligated at its origin and anastomosed distally to an 8-mm vascular graft, which was separately perfused to balance radial artery pressures bilaterally.

After aortic clamping, myocardial protection was achieved via antegrade infusion of cold crystalloid (Custodiol) or Del Nido cardioplegia. The left carotid artery (LCA) was ligated at its origin, cannulated distally, and perfused for ASCP. Following cardioplegic arrest, the innominate artery was proximally clamped, the aortic

balloon was inflated with the previously recorded volume, and the ECC femoral line was opened to ensure lower body perfusion. The aortic clamp was removed, and with uninterrupted lower body and cerebral perfusion, the proximal aorta was resected from the sinotubular junction to the endoprosthesis, creating a bloodless operative field.

A four-branched vascular graft was anastomosed to the distal aorta, with internal bites incorporating the endograft and external reinforcement with Teflon felt (*Figure 2*). The arch graft was clamped, the aortic balloon was deflated, and lower body perfusion was switched from the femoral line to the side branch of the graft to achieve antegrade flow. The proximal anastomosis between the graft and the aortic root was completed, and the heart was reperfused. The three arch vessels were individually anastomosed to the corresponding branches of the graft, completing the aortic reconstruction. The intervention was then completed as usual.

In five patients who had previously undergone thoracic endovascular aortic repair (TEVAR), slightly different approaches were adopted. Patients 1, 3, 11 and 13 presented with a type Ia endoleak, while patient 5 had a type A acute aortic dissection involving the ascending aorta and the proximal arch. In these cases, the same surgical technique was applied without deployment of a new endograft. Instead, a Reliant balloon was retrogradely introduced into the existing stent graft and inflated to achieve endoclamping. ECC was conducted via the innominate artery and femoral artery using a Y-connector, ensuring continuous perfusion of both the upper and lower body. The aorta was resected from the sinotubular junction to the distal end of the existing stent graft, and a four-branched vascular graft was anastomosed, incorporating the stent graft into the distal anastomosis. The procedure then followed the same steps as described above.

In patient 10, who presented with DeBakey type I acute aortic dissection with a large entry tear at the mid-aortic arch, the technique was further modified (10). A single femoral artery access was obtained. The aortic true lumen was catheterized under fluoroscopic and transesophageal echocardiographic guidance. ECC was initiated via cannulation of the non-dissected innominate artery and the right atrium. To address the large entry tear in the mid-aortic arch, the proximal landing zone between the innominate and left carotid arteries (zone 1) was identified and marked using multiple large hemoclips. The LSA was ligated and anastomosed distally to an 8-mm Dacron graft, while the LCA was ligated and cannulated. Both arteries

were perfused to enable ASCP. A 24-Fr, 66-cm DrySeal sheath (W.L. Gore, Phoenix, AZ, USA) was introduced through the femoral artery, and with the support of an extra-stiff guidewire, an appropriate endograft without a free-flow segment was cranially advanced and deployed at the marked landing zone. After deployment, the endograft shaft was removed, and the DrySeal sheath was advanced cranially, with its tip positioned securely inside the stent-graft. Through the same sheath, a Reliant balloon was introduced, followed by a 19-Fr arterial cannula connected via a Y-connector to the arterial line supplying the innominate artery. The balloon was inflated to clamp the aorta, and the femoral arterial line was opened, allowing uninterrupted antegrade perfusion of the distal dissected aorta. The intervention then proceeded as described above.

Inclusion criteria and procedural planning

Patient anatomy was carefully evaluated to ensure compatibility with the inclusion criteria. Distal landing zone dimensions and lengths were measured using centerline imaging. Oversizing of the endograft was planned at 15–20% for degenerative aneurysms and $\leq 5\%$ for acute dissection. The primary inclusion criterion for this procedure was the presence of an adequate distal landing zone for the endograft, enabling retrograde lower body perfusion and ensuring a bloodless operative field during the distal anastomosis. Exclusion criteria included (I) inadequate distal sealing zone; (II) severe aortic tortuosity; (III) absence of viable vascular access options; (IV) extreme aortic diameters; (V) active endocarditis; and (VI) chronic aortic dissection. For patients with acute type A aortic dissection, this approach was used selectively in stable cases, either with a clearly defined primary tear located in the aortic arch (patient 11), or in a patient who had previously undergone TEVAR (patient 5).

Statistical methods

Continuous variables were reported as medians with ranges, and categorical variables were expressed as absolute numbers and percentages. Descriptive statistics were used to summarize demographic characteristics, operative details, perioperative outcomes, and complications. No imputation was performed for missing data. Survival analysis was conducted using the Kaplan-Meier method, with overall survival calculated from the date of surgery to the last follow-up or death. Patients who were alive at

the time of last contact were censored. The Kaplan-Meier survival curve was generated to estimate cumulative survival probability over time. Due to the small sample size and exploratory nature of the study, no subgroup comparisons or hypothesis testing were performed. All statistical analyses were conducted using SPSS version 27.0 (IBM Corp., Armonk, NY, USA).

Results

Demographics and operative data

Between September 2019 and January 2025, 23 FET operations without HCA were performed at Polytechnic University of Marche. The median age of the patients was 73 years (range, 60–83 years), and 6 were female. EuroSCORE II ranged from 1.4% to 10% (median, 3.8%). Patients' characteristics are detailed in *Table 1*. Surgical indications included degenerative aneurysm in 14 patients, type I endoleak in four, acute dissection in two, chronic penetrating aortic ulcer in two, and Kommerell's diverticulum in one (*Table 2*).

All patients underwent total arch replacement with FET construction using a four-branched vascular graft and a stent graft. The stent graft was retrogradely deployed during the same procedure in 18 patients, while five patients (patients 1, 3, 5, 11 and 13) had previously undergone TEVAR. An LCA-LSA bypass was performed in four patients, while a right carotid-right subclavian artery (RCA-RSA) bypass was performed in three patients with an aberrant RSA. In all cases, the LSA or RSA was proximally occluded with a vascular plug. The stent graft coverage level ranged from zone 4 to zone 5. Intraoperative cerebrospinal fluid drainage was used in one patient, while in another case, it was positioned postoperatively due to transient paraparesis. Normothermic or mild hypothermic ECC was applied in 22 patients, while moderate hypothermia was used in one patient with type A acute dissection (patient 10). The median peak lactate level was 1.8 mmol/L (range, 1.0–4.8 mmol/L). Technical success was achieved in 100% of patients. Operative data are summarized in *Table 3*.

In-hospital outcomes and follow-up

In-hospital outcomes are summarized in *Table 4*. Within the first 30 days, two patients died: one due to septic shock (patient 12) and another due to postoperative stroke (patient 14). Major complications included temporary dialysis in four patients, stroke in three patients, and

Table 1 Aortic pathology and surgical indication

Patient No.	Index pathology	Disease extension-proximal	Disease extension-distal	Aberrant right subclavian artery	Maximum aortic diameter (mm)
1	Type I EL	Zone 0	Zone 1	Yes	78
2	Degenerative aneurysm	Zone 0	Zone 3	No	61
3	Type I EL, degenerative aneurysm	Zone 0	Zone 2	No	50
4	Degenerative aneurysm	Zone 2	Zone 3	No	54
5	Type-A AD	Zone 0	Zone 5	No	N/A
6	Degenerative aneurysm	Zone 0	Zone 3	No	52
7	Degenerative aneurysm	Zone 1	Zone 4	No	71
8	Kommerell's diverticulum	Zone 2	Zone 3	Yes	N/A
9	Degenerative aneurysm	Zone 0	Zone 9	Yes	77
10	Type-A AD	Zone 0	Zone 9	No	N/A
11	Type I EL	Zone 2	Zone 3	Yes	93
12	Degenerative aneurysm	Zone 0	Zone 3	No	56
13	Type I EL	Zone 0	Zone 4	No	51
14	Degenerative aneurysm	Zone 0	Zone 3	No	72
15	Degenerative aneurysm	Zone 0	Zone 4	No	60
16	Degenerative aneurysm	Zone 0	Zone 4	No	58
17	Degenerative aneurysm	Zone 2	Zone 3	No	45
18	Chronic PAU	Zone 3	Zone 3	No	45
19	Degenerative aneurysm	Zone 1	Zone 3	Yes	61
20	Chronic PAU	Zone 3	Zone 4	No	50
21	Degenerative aneurysm	Zone 0	Zone 5	No	56
22	Degenerative aneurysm	Zone 0	Zone 5	No	63
23	Degenerative aneurysm	Zone 0	Zone 4	No	55

AD, aortic dissection; EL, endoleak; N/A, not applicable; PAU, penetrating aortic ulcer.

respiratory insufficiency in three patients. The median intensive care unit (ICU) and hospital stays were 4 and 11 days, respectively. Postoperative computed tomography scans confirmed successful aortic repair in all cases, with one patient (patient 1) presenting a type II endoleak, which was initially managed conservatively.

Follow-up data are detailed in *Table 5*. The follow-up period ranged from 1 to 63 months (median, 27 months). Overall survival at 1, 2 and 3 years was $86.1\% \pm 7.5\%$, $69.8\% \pm 10.4\%$, and $69.8\% \pm 10.4\%$, respectively (*Figure 3*). Four patients died during follow-up due to myocardial infarction (n=2), sudden death (n=1), or an unknown cause

(n=1). Two patients experienced an ischemic stroke. A distal aortic reintervention was performed in three patients: two underwent TEVAR for a type Ib endoleak, while one patient with a type II endoleak (patient 1) underwent percutaneous embolization and surgical ligation of the intercostal arteries.

Discussion

HCA remains the principal limitation of aortic arch surgery, as it is associated with increased risks of neurological injury, organ dysfunction, and prolonged recovery (1-9). Recent evidence indicates that even short durations of

Table 2 Demographics

Patient No.	Age (years)	Sex	Comorbidities	Previous surgery	Preoperative status	Euroscore II (%)
1	79	Male	aHT; chronic renal failure	Extra-anatomical RCCA-LCCA-LSA, TEVAR (zone 1)	Elective	6.4
2	72	Male	aHT; AF; obesity; chronic renal failure	No	Elective	1.8
3	81	Female	aHT; COPD; CVD; CAD; chronic renal failure	LCCA-LSA bypass, RCIA-RCFA bypass, TEVAR (zone 2)	Elective	10.0
4	79	Male	aHT; COPD; CAD; chronic renal failure	No	Elective	2.7
5	73	Female	aHT	TEVAR (Zone 3)	Emergency	3.4
6	67	Male	aHT; AF; chronic renal failure	No	Elective	8.0
7	78	Male	aHT; COPD; PAD; chronic renal failure	TEVAR (Zone 4)	Elective	4.3
8	79	Male	Type II DM; CVD; CAD; chronic renal failure	No	Elective	3.5
9	77	Male	aHT; type II DM; COPD; PAD; chronic renal failure	Ascending aorta replacement	Elective	4.3
10	60	Male	aHT; obesity; CVD; PAD; AF; obesity	No	Emergency	3.6
11	65	Male	aHT; AF; chronic renal failure	Extra-anatomical RCCA-LCCA-LSA, TEVAR (zone 1) David procedure and partial arch replacement	Elective	4.4
12	72	Female	aHT; PAD; COPD; chronic renal failure	No	Elective	6.4
13	72	Male	aHT; chronic renal failure	TEVAR (zone 2)	Elective	4.0
14	82	Male	aHT	EVAR (zone 8)	Elective	4.1
15	83	Male	aHT; AF; previous PMK	No	Elective	2.7
16	69	Female	aHT	AVR, ascending aorta replacement	Elective	5.0
17	69	Male	aHT	No	Elective	1.4
18	76	Male	aHT; CVD	No	Elective	2.7
19	72	Female	aHT	No	Elective	3.1
20	75	Male	aHT; AF; chronic renal failure	No	Elective	6.2
21	71	Male	aHT; chronic renal failure	No	Elective	3.7
22	73	Male	aHT; obesity; COPD	No	Elective	2.9
23	80	Female	aHT; CVD; COPD	No	Elective	3.8

AF, atrial fibrillation; aHT, arterial hypertension; AVR, aortic valve replacement; CAD, coronary artery disease; COPD, chronic obstructive pulmonary disease; CVD, cerebrovascular disease; DM, diabetes mellitus; EVAR, endovascular aneurysm repair; IA, innominate artery; LCCA, left common carotid artery; LSA, left subclavian artery; N/A, not applicable; PAD, peripheral arterial disease; PMK, pacemaker; RCCA, right common carotid artery; RCFA, right common femoral artery; RCIA, right common iliac artery; TEVAR, thoracic endovascular aortic repair.

Table 3 Operative data													
Patient No.	Operation	Arterial cannulation site	Distal anastomosis	Endograft size (mm)	Distal landing zone	CPB time (min)	Cross clamp time (min)	Cerebral perfusion time (min)	Lower temperature (°C, rectal)	Urine output during CPB (mL)	Cardioplegia	Intra-operative peak lactates (mmol/L)	First post-operative lactates value (mmol/L)
1	Total arch replacement, CABG	RAA & LFA	Zone 1	N/A	N/A	91	53	65	32	250	Custodiol	2.7	1.4
2	FET	IA & RFA	Zone 2	34-34-90	Zone 4	120	56	69	32	850	Custodiol	1.4	1.0
3	Total arch replacement	IA & RFA	Zone 2	N/A	N/A	106	61	69	30	150	Custodiol	1.9	1.5
4	FET, AVR	IA & RFA	Zone 2	31-31-182	Zone 4	86	72	73	32	700	Custodiol	1.9	1.8
5	Total arch replacement	RAA & RFA	Zone 2	N/A	N/A	121	75	87	32	180	Custodiol	1.8	2.7
6	FET, Bentall	IA & RFA	Zone 2	37-37-90	Zone 4	171	125	45	31	360	Custodiol	1.3	1.3
7	FET	IA & LFA	Zone 2	40-40-218 40-40-97	Zone 5	104	51	61	32	700	Custodiol	1.2	1.1
8	FET, RCCA-RSA bypass	RFA	Zone 2	31-31-90	Zone 4	101	50	70	32	400	Custodiol	1.0	1.1
9	First stage: LCCA-LSA/RCCA-RSA bypass Second stage: FET	RFA & PAG	Zone 1	31-31-182 31-31-223	Zone 5	144	42	111	28	125	Custodiol	3.2	2.7
10	FET	IA	Zone 2	37-37-182	Zone 4	205	79	130	26	180	Custodiol	3.2	2.7
11	Total arch replacement	LAA & RFA	Zone 1	N/A	N/A	116	85	97	34	140	Custodiol	1.2	1.4
12	First stage: LCCA-LSA bypass, LCIA-LFA bypass, TEVAR (zone 2) Second stage: FET	RAA & LFA	Zone 2	40-34-200 46-40-200	Zone 5	109	69	79	32	150	Custodiol	2.2	2.4
13	Total arch replacement	IA	Zone 2	N/A	N/A	98	49	66	28	350	Custodiol	1.3	1.2
14	FET	IA & RFA	Zone 2	38-38-154	Zone 4	152	106	120	36	300	Del Nido	1.2	1.1
15	First stage: LCCA-LSA bypass Second stage: FET	IA & RFA	Zone 2	40-40-204	Zone 4	126	70	84	30	300	Custodiol	2.0	1.4
16	FET	IA & LFA	Zone 2	32-32-104	Zone 4	119	50	65	33	650	Del Nido	1.9	4.8
17	First stage: LCCA-LSA bypass Second stage: FET	IA & RFA	Zone 2	34-34-154	Zone 4	90	56	58	30	300	Del Nido	2.3	3.8
18	FET	IA & LFA	Zone 2	28-28-164	Zone 4	83	42	52	35	400	Del Nido	1.3	1.3
19	First stage: RCCA-RSA bypass Second stage: FET	RAA & LFA	Zone 2	28-28-164	Zone 4	126	72	83	35	580	Custodiol	1.6	2.1
20	FET	IA & LFA	Zone 2	38-38-154	Zone 5	97	61	65	36	500	Del Nido	1.8	3.0
21	FET	IA & RFA	Zone 2	38-38-154	Zone 4	65	55	60	35	420	Del Nido	1.7	1.2
22	FET	IA & LFA	Zone 2	32-32-164	Zone 5	112	55	70	36	470	Custodiol	2.1	1.6
23	FET	IA & RFA	Zone 2	38-38-154	Zone 4	81	47	58	33	320	Custodiol	1.6	2.3

AVR, aortic valve replacement; CABG, coronary artery bypass grafting; CPB, cardiopulmonary bypass; FET, frozen elephant trunk; IA, innominate artery; LAA, left axillary artery; LCCA, left common carotid artery; LCIA, left common iliac artery; LFA, left femoral artery; LSA, left subclavian artery; N/A, not applicable; PAG, prosthetic aortic graft; RAA, right axillary artery; RCCA, right common carotid artery; RFA, right femoral artery; RSA, right subclavian artery; TEVAR, thoracic endovascular aortic repair.

Table 4 Post-operative outcomes

Patient No.	Stroke	Dialysis	Spinal cord injury	Drain leakage ≤12 h (mL)	Bleeding (requiring revision)	RBC post-operative transfusion (units)	Intubation time (hours)	Respiratory insufficiency	ICU stay (days)	Death (cause)	Hospital stay (days)
1	No	No	No	240	No	1	20	No	3	No	7
2	No	No	No	800	No	3	6	No	1	No	9
3	No	No	No	150	No	3	7	No	4	No	7
4	No	No	No	410	No	4	31	No	6	No	10
5	No	No	No	240	No	2	20	No	3	No	7
6	No	No	No	550	No	5	21	No	2	No	15
7	No	No	No	260	No	0	12	No	1	No	7
8	No	No	No	289	No	0	6	No	4	No	14
9	No	No	No	170	No	0	15	No	1	No	14
10	No	No	No	250	No	10	15	No	2	No	21
11	No	No	No	500	No	7	10	No	1	No	7
12	No	Temporary	No	200	No	34	700	Re-OTI + tracheostomy	98	Septic shock	141
13	No	No	No	570	No	3	5	No	3	No	6
14	Yes	Temporary	Temporary paraparesis	300	Yes	11	360	Re-OTI + tracheostomy	16	Neurological	16
15	Yes	Temporary	No	1,290	No	18	45	Re-OTI + tracheostomy	43	No	84
16	Yes	Temporary	No	1,050	Yes	11	140	No	15	No	41
17	No	No	No	420	No	2	20	No	5	No	13
18	No	No	No	250	No	1	6	No	4	No	8
19	No	No	No	350	No	3	5	No	5	No	15
20	No	No	No	300	No	3	8	No	7	No	10
21	No	No	No	445	No	2	5	No	4	No	6
22	No	No	No	350	No	0	7	No	3	No	11
23	No	No	No	420	No	4	6	No	2	No	8

ICU, intensive care unit; OTI, orotracheal intubation; RBC, red blood cells.

HCA (<20 minutes) result in cognitive deficits in 40% of patients, including those receiving ASCP, with documented neuroimaging lesions (1). This confirms that no duration of HCA can be considered completely safe, as even short periods may result in brain injury. Therefore, research and technological advancements should focus on developing techniques that eliminate the need for HCA during arch repair.

Surgical technique and indications

At our center in Ancona, through close collaboration between cardiac and vascular surgeons within the Aortic Team, we have developed a technique that enables FET procedures to be performed without circulatory arrest, with normothermia maintained throughout. By combining surgical and endovascular techniques, this approach ensures

Table 5 Follow-up

Patient No.	FU time (months)	Death	Stroke	Distal aortic redo	Cause of distal aortic procedure	Other cardiac procedure	Cause of other cardiac procedure
1	63	No	No	Intercostal artery embolization Surgical ligations of the intercostal artery Intercostal artery embolization	Type II EL	PTCA	VG occlusion
2	63	No	Yes	No	N/A	No	N/A
3	62	No	No	EVAR	Type I EL	No	N/A
4	4	Yes	No	No	N/A	No	N/A
5	58	No	No	No	N/A	No	N/A
6	17	Yes	No	TEVAR	Type I EL	No	N/A
7	54	No	No	No	N/A	No	N/A
8	53	No	Yes	No	N/A	No	N/A
9	22	Yes	No	No	N/A	No	N/A
10	52	No	No	No	N/A	No	N/A
11	12	Yes	No	No	N/A	No	N/A
12	N/A	Hospital death	No	N/A	N/A	N/A	N/A
13	48	No	No	No	N/A	No	N/A
14	N/A	Hospital death	No	N/A	N/A	N/A	N/A
15	29	No	No	No	N/A	No	N/A
16	29	No	No	No	N/A	No	N/A
17	27	No	No	No	N/A	No	N/A
18	25	No	No	No	N/A	No	N/A
19	21	No	No	No	N/A	No	N/A
20	17	No	No	No	N/A	No	N/A
21	6	No	No	No	N/A	No	N/A
22	4	No	No	No	N/A	No	N/A
23	1	No	No	No	N/A	No	N/A

EL, endoleak; EVAR, endovascular aneurysm repair; FU, follow-up; N/A, not applicable; PTCA, percutaneous transluminal coronary angioplasty; TEVAR, thoracic endovascular aortic repair; VG, venous graft.

continuous cerebral and systemic perfusion, potentially addressing longstanding challenges in aortic arch surgery. The ideal candidates for this technique are patients with degenerative aneurysms or penetrating aortic ulcers who have an adequate distal landing zone for proper stent graft sealing. Indeed, this approach is not applicable to patients with chronic dissections and is only suitable for

selected acute dissection cases with favorable anatomy. In our experience, two acute dissection patients were treated: patient 5, who had previously undergone TEVAR prior to the acute dissection, and patient 10, who had a single primary tear in the mid-aortic arch and was clinically stable at presentation. Additional limitations of this technique include the increased complexity and bleeding risk

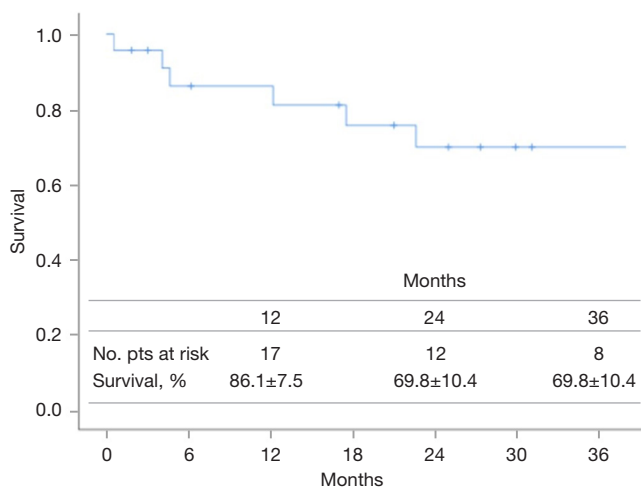


Figure 3 Kaplan-Meier survival curve. pts, patients.

associated with the distal anastomosis to the endograft, as well as its more technically demanding nature compared to conventional FET. This operation requires advanced hybrid operating room facilities and significant surgical expertise in both open and endovascular procedures, which may not be universally available. Nevertheless, we achieved a 100% technical success rate in this series, supporting the feasibility of our technique.

Preliminary results

Given the complexity and high-risk profile of the study cohort, the observed outcomes were satisfactory, providing preliminary evidence of the safety and effectiveness of the technique. In the present series, two patients died during the hospital stay (patients 12 and 14). Patient 12 was a high-risk female with severe peripheral vasculopathy, advanced renal failure (stage IIIb) and severe chronic obstructive pulmonary disease. Given her complex vascular status, which was anatomically unfeasible for total endovascular arch repair, a staged hybrid repair was performed. In the first stage, she underwent zone 2 TEVAR via left common iliac artery (LCIA) access, along with an LCA-LSA bypass, endovascular LSA occlusion, and an LCIA-left common femoral artery (LCFA) bypass. In the second stage, FET construction was completed using the previously created LCIA-LCFA bypass as the arterial inflow site for ECC. Although the procedure was technically successful, postoperative recovery was complicated. After initial extubation, she developed pneumonia, respiratory

insufficiency and acute kidney injury on postoperative day four, requiring reintubation, tracheostomy and dialysis. Despite intensive care support, she ultimately died due to septic shock. The second in-hospital death (patient 14) was an elderly male (82 years) who suffered, during uneventful post-operative course, a major stroke four days after the operation.

Spinal cord injury is a well-documented complication of conventional FET, with its risk increasing proportionally to the extent of aortic coverage (16). In our series, despite the extensive stent graft coverage, no cases of spinal cord injury were observed. This finding suggests a potential protective advantage of our technique over traditional approaches, likely due to the continuous body perfusion maintained throughout the procedure. Supporting this hypothesis, a key observation of our study was that intraoperative lactate levels remained within near-normal values in all patients (*Table 3*), indicating preserved perfusion of both the upper and lower body.

Indeed, unlike previously reported techniques aimed at reducing HCA (17), our approach completely eliminates the need for circulatory arrest and simultaneously maintains normothermic ECC, ensuring a bloodless and maneuverable operative field. This is achieved through retrograde balloon advancement into the stent graft for aortic clamping, rather than an antegrade approach. We believe this could improve patient outcomes by reducing ischemia-reperfusion injury during the operation. Nevertheless, a larger cohort is required to validate this hypothesis.

Limitations

This study was conducted as a single-center, retrospective analysis, limiting its external validity. The absence of control cases further restricts the ability to draw definitive comparisons between this technique and traditional methods involving HCA. The relatively small patient cohort reduces the statistical power of the study and may not capture the full range of potential complications or long-term outcomes. Our series includes a highly selective population, with patients chosen based on anatomical compatibility and clinical stability, potentially skewing the results toward more favorable outcomes.

Conclusions

Normothermic FET without circulatory arrest represents

a promising evolution in aortic arch surgery. Our initial experience demonstrated a high technical success rate and favorable clinical outcomes in selected patients. However, larger cohort studies are needed to validate these findings and assess the broader applicability of the technique.

Acknowledgments

None.

Footnote

Funding: None.

Conflicts of Interest: The authors have no conflicts of interest to declare.

Open Access Statement: This is an Open Access article distributed in accordance with the Creative Commons Attribution-NonCommercial-NoDerivs 4.0 International License (CC BY-NC-ND 4.0), which permits the non-commercial replication and distribution of the article with the strict proviso that no changes or edits are made and the original work is properly cited (including links to both the formal publication through the relevant DOI and the license). See: <https://creativecommons.org/licenses/by-nc-nd/4.0/>.

References

- Hughes GC, Chen EP, Browndyke JN, et al. Neurocognitive Dysfunction After Short (<20 Minutes) Duration Hypothermic Circulatory Arrest. *Ann Thorac Surg* 2025;119:343-50.
- Nakamura K, Onitsuka T, Yano M, et al. Risk factor analysis for ascending aorta and aortic arch repair using selective cerebral perfusion with open technique: role of open-stent graft placement. *J Cardiovasc Surg (Torino)* 2006;47:659-65.
- Khaladj N, Shrestha M, Meck S, et al. Hypothermic circulatory arrest with selective antegrade cerebral perfusion in ascending aortic and aortic arch surgery: a risk factor analysis for adverse outcome in 501 patients. *J Thorac Cardiovasc Surg* 2008;135:908-14.
- Di Eusanio M, Berretta P, Cefarelli M, et al. Total Arch Replacement Versus More Conservative Management in Type A Acute Aortic Dissection. *Ann Thorac Surg* 2015;100:88-94.
- Mousavizadeh M, Daliri M, Aljadayel HA, et al. Hypothermic circulatory arrest time affects neurological outcomes of frozen elephant trunk for acute type A aortic dissection: A systematic review and meta-analysis. *J Card Surg* 2021;36:3337-51.
- Czerny M, Krähenbühl E, Reineke D, et al. Mortality and neurologic injury after surgical repair with hypothermic circulatory arrest in acute and chronic proximal thoracic aortic pathology: effect of age on outcome. *Circulation* 2011;124:1407-13.
- Svensson LG, Crawford ES, Hess KR, et al. Deep hypothermia with circulatory arrest. Determinants of stroke and early mortality in 656 patients. *J Thorac Cardiovasc Surg* 1993;106:19-28; discussion 28-31.
- Cao L, Guo X, Jia Y, et al. Effect of Deep Hypothermic Circulatory Arrest Versus Moderate Hypothermic Circulatory Arrest in Aortic Arch Surgery on Postoperative Renal Function: A Systematic Review and Meta-Analysis. *J Am Heart Assoc* 2020;9:e017939.
- Tian DH, Wan B, Di Eusanio M, et al. 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;2:581-91.
- Di Eusanio M, Gatta E. Frozen Elephant Trunk Without Circulatory Arrest in Acute Aortic Dissection. *Ann Thorac Surg* 2021;112:e143-5.
- Di Eusanio M, Cefarelli M, Alfonsi J, et al. Arch Surgery for Type Ia Endoleak: How to Remain Normothermic and Avoid Circulatory Arrest. *Ann Thorac Surg* 2020;110:e139-41.
- Di Eusanio M, Cefarelli M, Alfonsi J, et al. Normothermic frozen elephant trunk surgery without circulatory arrest: how we do it in Ancona. *Ann Cardiothorac Surg* 2020;9:244-5.
- Rylski B, Pacini D, Beyersdorf F, et al. Standards of reporting in open and endovascular aortic surgery (STORAGE guidelines). *Eur J Cardiothorac Surg* 2019;56:10-20.
- Czerny M, Grabenwöger M, Berger T, et al. EACTS/STS Guidelines for diagnosing and treating acute and chronic syndromes of the aortic organ. *Eur J Cardiothorac Surg* 2024;65:ezad426. Erratum in: *Eur J Cardiothorac Surg* 2024;65:ezae235.
- Nashef SA, Roques F, Sharples LD, et al. EuroSCORE II. *Eur J Cardiothorac Surg* 2012;41:734-44; discussion 744-5.
- 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;160:20-33.e4.

17. Malvindi PG, Alfonsi J, Berretta P, et al. Normothermic frozen elephant trunk: our experience and literature review. *Cardiovasc Diagn Ther* 2022;12:262-71.

Cite this article as: Berretta P, D'Alessio S, Malvindi PG, D'Alfonso A, Cefarelli M, Galeazzi M, Bifulco O, Giusti M, Vento V, Spagnolo F, Gatta E, Di Eusanio M. Frozen elephant trunk in normothermia without circulatory arrest: initial experience. *Ann Cardiothorac Surg* 2025;14(4):291-302. doi: 10.21037/acs-2025-evet-0042