Standardized total arch replacement using the frozen elephant trunk technique

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Clinical vignette

A 35-year-old male with an aortic arch aneurysm was under follow-up. His history included neonatal repair of aortic coarctation with a Dacron patch. Computed tomography (CT) revealed a 55 mm × 61 mm pseudoaneurysm at the isthmus, a 39 mm proximal descending thoracic aorta, and a 24 mm proximal left subclavian artery (LSA). Based on these findings, total aortic arch replacement with frozen elephant trunk (FET) was planned.

Surgical techniques

Preparation

Prior to intervention, angio-CT assessment is conducted to measure the aortic diameter in patients with aneurysms and the true lumen diameter in those with aortic dissection. This measurement is taken from the outer-to-outer edge at the anticipated distal positioning of the stent graft. In cases of dissection, oversizing is avoided to limit distal stent graft-induced new entry (dSINE), and the sizing is based on the maximum true lumen diameter, whereas in patients with chronic aneurysms, oversizing ranges from 10% to 20%. General anesthesia is administered, and a central venous catheter is inserted. Arterial monitoring is conducted via bilateral radial and left femoral arteries. Near-infrared spectroscopy (NIRS) probes are employed to monitor bilateral cerebral oxygen saturation. Bladder and nasopharyngeal temperature probes are utilized for core temperature monitoring. A mean arterial pressure >85 mmHg and hematocrit >30% are maintained in the first post-operative days. Cerebrospinal fluid drainage is only used for 150-mm grafts.

Exposition

All FET procedures are conducted via median sternotomy. The pericardium is incised longitudinally and suspended with traction sutures. The supra-aortic vessels are meticulously dissected and encircled with umbilical tapes.

Operation

Interventions are performed via cardiopulmonary bypass

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(CPB), under mild hypothermic circulatory arrest (26 ℃) combined with bilateral antegrade selective cerebral perfusion (ASCP) with a flow rate of 12 mL/kg/min and CO_2 insufflation to prevent air embolism. Myocardial protection is achieved through antegrade cardioplegia.

Cannulation strategies are individualized according to clinical presentation and pre-operative CT scan. Femoral artery cannulation is reserved for unstable patients or complex reoperations, allowing rapid institution of CPB prior to sternotomy. In patients with aortic aneurysms, it is possible to perform direct ascending aorta cannulation. In stable patients, the brachiocephalic trunk (BCT) or axillary artery is preferentially cannulated to facilitate early ASCP. Carotid artery cannulation is employed in acute dissections when it represents the only non-dissected supra-aortic vessel, and in chronic cases with challenging re-entry, enabling unilateral cerebral perfusion.

In this case, arterial cannulation is performed via the ascending aorta with atrial venous drainage and a right superior pulmonary vein vent. Upon reaching the nasopharyngeal temperature of 26 ℃, the aorta is clamped and cardioplegia is administered. The LSA is clamped distally and ligated proximally with a large Teflon pledget and secured with double-sutures. Following opening and mobilization of the ascending aorta, the BCT and left carotid artery (LCA) are clamped.

Following initiation of circulatory arrest, the aortic clamp and the arterial cannula are removed and the arch is resected in Zone 2. Bilateral ASCP is maintained using two True Flow RDB cannulas (European Medical Supplies, S.R.L., Bologna, Italy) in the BCT and LCA. The distal anastomosis is reinforced with two or three large internal pledgets and an external Teflon strip. The descending thoracic aorta is inspected using an angioscope to confirm true-lumen identification and detect fenestrations or entry tears. The 150 mm hybrid stent-graft is deployed antegrade over a femoral guidewire, after checking its position in the true lumen by transesophageal echocardiography. With shorter stent-grafts, the use of the guidewire is not necessary. After completing the distal anastomosis with a continuous 3/0 suture, proper deployment is verified via angioscopy.

Visceral perfusion is restored through the Thoraflex side branch, followed by systemic de-airing and rewarming. The LSA is reimplanted into its dedicated graft branch with external Teflon reinforcement. The proximal anastomosis is then completed using an external Teflon felt. The aorta is declamped and coronary artery reperfusion is restarted. The LCA and BCT are anastomosed with continuous suture to their respective graft branches after sequential removal of cerebral perfusion cannulas. Meticulous de-airing is performed at every anastomotic stage.

Completion

Once hemodynamic stability is achieved, CPB is discontinued. Meticulous hemostasis is ensured, and the pericardium is closed over the prosthesis. Sternal closure is performed in a standard fashion.

Comments

Clinical results

Our experience with the FET technique began in 2007. By December 2025, 442 procedures were performed for aortic aneurysm (27.2%), acute type A or B aortic syndromes (21.5%) and chronic type A or B aortic syndromes (51.6%), the latter including residual dissections. Notably, 52.7% of patients had previous cardiac surgery.

Postoperative stroke and paraplegia rates are 6.1% and 2.7%, respectively. Most strokes were ischemic (70%), while 30% were hemorrhagic; 50% occurred in patients with residual dissection after previous aortic surgery. After adoption of a standardized Zone 2 strategy with shorter stent-graft coverage, paraplegia became rare in the last five years. Thirty-day mortality was 11.8%, with 69% of deaths occurring in patients presenting with acute or residual dissection, often in redo settings. Median follow-up was 50.5 months (interquartile range, 9.3–91.8 months). Kaplan-Meier estimated overall survival reached 67.2% at 5 years and 51% at 10 years.

During follow-up, 32.8% of patients required distal extension with thoracic endovascular aortic repair (TEVAR), mostly as planned staged procedures in extensive chronic or residual dissections; 52% were performed in patients with pre-existing residual dissection. Among unplanned reinterventions, dSINE was the leading indication (37% of all TEVAR extension).

Overall, dSINE occurred in 64 patients (14.4%). In the subgroup treated with Zone 2 distal anastomosis and a 100 mm Thoraflex graft, dSINE occurred in 24/186 patients (12.9%).

Advantages

Our current FET strategy focuses on technical standardization to optimize clinical outcomes. Shifting the distal anastomosis from Zone 3 to Zone 2, combined with distal clamping, proximal ligation of the LSA, and separate graft branch reimplantation, significantly simplifies arch repair and hemostasis (1). This strategy minimizes visceral ischemia, cross-clamp times, and recurrent laryngeal nerve injury, while offering a safer and more accessible surgical field compared to Zone 3. Although shorter stent-graft coverage and proximal descending aortic landing may theoretically increase dSINE risk, our experience with the 100 mm Thoraflex graft has shown acceptable dSINE rates even in a cohort largely composed of chronic and residual dissections. Angioscopy allows an extremely precise control of the deployment (2).

Concurrently, we transitioned from E-vita Open prosthesis to Thoraflex^{TM} Hybrid device, which has been adopted in most cases since 2014. Its multibranched configuration facilitates standardized, branch-by-branch supra-aortic vessel reimplantation and enables earlier distal reperfusion. Compared with earlier-generation devices, this has enhanced procedural efficiency in complex anatomies (3).

The supra-aortic reimplantation technique evolved from an island configuration to systematic separate anastomoses, fully standardized by 2018. This approach provides superior control of individual anastomotic sites, reduces cross clamp times, and decreases the risk of pseudoaneurysm (4).

To mitigate spinal cord ischemia, we progressively shortened the stent-graft length to 100 mm, without compromising distal remodeling (5). We use 150 mm grafts when this allows us to achieve an effective seal or cover the entire diseased segment. In these cases, deployment is performed over a femoral guidewire placed under transesophageal echocardiography.

Caveats

Meticulous mobilization of the supra-aortic vessels is essential to facilitate safe and tension-free reimplantation. Cannulation strategy is equally critical: whenever feasible, axillary or BCT cannulation allows immediate ASCP, providing an additional safeguard in case of complications. We strongly advocate for routine bilateral ASCP, which has proven protective over time in our experience. Finally, Teflon felt reinforcement of both proximal and distal anastomoses is essential when managing fragile, diseased aortic tissue to enhance durability and minimize bleeding.

In order to prevent major complications, clinicians should avoid performing a Zone 2 anastomosis with short stent-grafts in patients with a gothic or highly angulated aortic arch, as this anatomy carries a high risk of stent-graft kinking. Furthermore, stent-graft oversizing must be avoided in acute or chronic dissections to minimize the risk of aortic rupture and late dSINE.

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Footnote

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