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Review

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Total endovascular aortic arch repair: is it for everyone and where is its evidence?

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Abstract

Open total arch replacement (TAR) remains the mainstay management strategy for thoracic aortic diseases involving the aortic arch. TAR evolved from the 2-stage conventional elephant trunk (CET) technique to the hybrid frozen elephant trunk (FET) which combined open surgical repair (OSR) with thoracic endovascular aortic repair (TEVAR) into a 1-stage procedure. Although FET has been able to achieve superior results to CET, including excellent survival, it still carries a risk of certain complications that may even require secondary reintervention. The era of elephant trunk is being overtaken by the new generation of TEVAR devices being used for total endovascular aortic arch (or endoarch) repair. Total endoarch repair (TER) is currently indicated in patients deemed high-risk for open surgery; however, it has shown strong potential for becoming the gold stand treatment for aortic arch pathologies. Despite the minimally-invasive nature of TER providing an obvious advantage over OSR in certain cases, TER remains associated with comparable mortality rates and key complications such as technical failure, neurological injury, need for reintervention, and loss of or failure to achieve target vessel patency. Upon comprehensively searching the literature, the technical success of TER ranged from 91%-100%, mortality 0%-19%,

stroke 0%-16.7% and reintervention 0%-30.3%, using different commercially available endografts. Given its novelty, further studies with larger cohorts and longer follow-up periods are necessary to solidify the evidence on TER, taking into account the significant learning curve associated with TEVAR. In addition, studies directly comparing arch OSR to TER are warranted to determine superiority. This review aimed to highlight the evolution of aortic arch repair, focusing on TER device development, intervention criteria and clinical outcomes.

Keywords: Thoracic aortic disease, aortic arch, endovascular, endoarch, TEVAR

INTRODUCTION

Open total arch replacement (TAR) remains the gold standard surgical approach for thoracic aortic pathologies involving the aortic arch. The reported mortality and morbidity for elective aortic arch repair are highly variable. Culpable to this overwhelming morbidity and mortality variations are correlated to patients undergoing cardiopulmonary bypass (CPB) and hypothermic circulatory arrest (HCA), in addition to risks associated with general anaesthesia. The main two techniques for TAR are the conventional elephant trunk (CET) and frozen elephant trunk (FET)[1].

Over the past decade, the thoracic endovascular approach for aortic arch (or endoarch) repair gained momentum, especially in high-risk population groups, thanks to the innovation and application instrumented by device technology endograft suppliers and the enthusiasm of endovascular surgeons. As such, endografts became available for investigational purposes in the aortic arch profile and as part of investigational device exemption programs. To this effect, certain devices are supplied fenestrated or scalloped, while others are branched, albeit single-, double-, or triple-branched stent-grafts. Such technology optimized options for aortic arch repair in high-risk patients who were deemed inoperable, which decreases the associated risk of perioperative mortality and morbidity[2,3]. However, reported series on the use of the endovascular approach in aortic arch profile continued to encounter relatively high complication rates and poor operative outcomes[4]. This can be partly attributed to revascularization requirement as well as the substantial risk of stroke due to wire and device manipulation within the aortic arch aneurysm, which is a drawback[5]. In addition, this can also be attributed to the high-risk patient population treated. Graft patency, re-intervention rates, long-term comparative functionality, and durability of endoarch were uncertain[2,4,5]. Additionally, surgeon volume-outcome linearity, learning curve, and decision-making were key factors for total endoarch repair (TER) to be considered sustainable.

In this review, we sought to highlight the TER approach, including device evolution, intervention criteria and clinical outcomes, and set the scene in a comparative mode to open surgical aortic arch repair as well as dwell on the current trend of hybridized approaches using FET which evolved from CET.

METHODS

A comprehensive literature search was performed using major search engines (PubMed, Google Scholar, EMBASE and Scopus) to search all scientific articles published as of July 2022. The search terms used included: “Aortic Dissection”, “Aortic Aneurysm”, “Conventional Elephant Trunk (OR CET)”, “Frozen Elephant Trunk (OR FET)”, “Thoracic Aorta”, “Aortic Arch”, “Endovascular”, “Endovascular Arch Repair”. Additional sources were identified by individually reviewing reference lists of included publications.

Past to present: an overview of aortic arch surgical repair

Conventional vs. frozen elephant trunk

FET and CET (evaluated in Table 1) are similar in terms of the scope of repair of the ascending aorta and the aortic arch. In both approaches, the entire transverse aortic arch is completely replaced, with a variable portion of the ascending aorta replaced, leaving a significant portion of unrepaired thoracoabdominal aorta. Both approaches also successfully mitigate damage to important anatomical structures (e.g., vagus and recurrent laryngeal nerves, oesophagus, pulmonary artery, and thoracic duct). The primary difference between the FET and CET is centred on how the dissected portion of the distal thoracic aorta (DTA) is managed. In the first stage of CET, the dissected proximal DTA is left unrepaired for an inevitable second-stage procedure, which introduces higher cumulative surgical risk and interval mortality, and it is likely to be unsuccessful in sealing the false lumen[6-14]. However, FET combines CET and thoracic endovascular aortic repair (TEVAR) into a single-step hybrid procedure using a hybrid prosthesis to replace the ascending aorta and arch and repair the dissected proximal DTA in the same operation[15]. There is emerging evidence from multiple studies to support that FET performs stronger than CET, with the exception of spinal cord injury[16,17].

Best of both worlds: OSR and TEVAR

The introduction of the FET technique for TAR has revolutionised the field of aortic surgery. Since then, it has become a vital element in the aortic surgeon's armamentarium. Importantly, the FET surgical approach is variable; thus, it is actually flexible rather than frozen, as it can be tailored to individual clinical scenarios and has the potential to be used in all aortic profiles[18].

FET is associated with good survival, both in the short and long terms. Upon searching the literature, 30-day mortality rates ranged from 0%-15%, while long-term mortality was low, with one study reporting 100% survival at 3 years post-discharge[19-21]. Aortic remodelling is well-established in the literature as an important prognostic factor in AD patients following FET. Two recent reviews by Jubouri *et al.* and Kayali *et al.* showed beyond doubt that FET promotes superior aortic remodelling to CET[22,23]. Remodelling is also observed distally in the descending thoracic aorta and abdominal aorta due to the extended coverage of the stent-graft portion of the FET hybrid device. Although FET has proven its high safety and effectiveness, it still carries a risk of complications, with some even requiring secondary reintervention[15]. Another study by Kayali *et al.*, along with the aforementioned Geragotellis *et al.* and Jubouri *et al.*, all demonstrated the low incidence of complications post-FET as well as the minimal need for secondary reintervention[15,22,24].

Interestingly, TER has shown strong potential for becoming the primary management strategy for dissections and aneurysms of the thoracic aorta instead of FET. Furthermore, although the continuingly increasing uptake of FET has meant that several FET hybrid prostheses have become commercially available, the era of FET device development is being overtaken by the new generation of devices for endoarch repair using TEVAR, marking a turning point in the management strategy of thoracic aortic disease.

The future: total endovascular arch repair

Device evolution

Since TEVAR was first introduced in 1994, it has become one of the main strategies for tackling a range of thoracic aortic pathologies. The first TEVAR device was approved later on in 2005 and was initially used in the treatment of aortic aneurysmal disease. Thereafter, TEVAR indications expanded to include other aortic pathologies, including type B dissections and penetrating ulcers[25,26]. TEVAR has also gradually become an option for endovascularly treating dissections and aneurysms involving the aortic arch and root, offering

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

	FET	CET
Advantages	1-stage procedure (risk of reintervention)	Simplifies distal aortic arch anastomosis, reducing the risk of visceral ischemic complications
	Minimal graft kinking	Lower rates of spinal cord injury
	Reduces risk of repeat aortic surgery via better FL thrombosis	
Disadvantages	Higher rates of spinal cord injury	2-stage procedure - high cumulative surgical risk
		Interval mortality
		May fail to address residual FL patency
		Graft kinking

the potential to replace OSR via CET and FET. Still, endovascular control of the torque may be severely limited by the anteroposterior and mediolateral curvature of the proximal aorta. Thus, the accurate placement and positioning of the device remain challenging and the use of antegrade and retrograde guiding wires may be necessary to improve technical control[27]. Several endoarch devices are commercially available on the market globally, employing both branched and fenestrated TEVAR.

The RELAY™ Branched, developed by Terumo Aortic, is a well-recognized example of branched TEVAR for treating aortic arch pathologies. The RELAY™ device features a branched system for retrograde endovascular delivery through femoral or iliac access. The design of the pre-curved inner catheter and dual sheath conforms to the alignment with the curvature of the arch and ascending aorta. Furthermore, employing support wires helps to reduce intra-aortic instrumentation and serves to ease positioning during implantation. The main body of the RELAY™ Branched system has a window situated on the dorsal aspect of the endograft, which facilitates the cannulation of one, two, or all three supra-aortic vessels using either a single-, double-, or triple-branched device, respectively. This window is labelled with radiopaque markers to outline the device's positioning and orientation in relation to the supra-aortic vessels. Importantly, the design of TEVAR endoprostheses and their technical considerations during deployment have continually evolved. The different branch configurations of the RELAY™ endoprosthesis are illustrated in Figure 1. Examples of other commercially available TER devices are shown in Figure 2.

Careful evaluation of the landing zone is imperative. In cases of dissection, it is measured using the distance from the coronary ostia and the sinotubular junction to the proximal entry of the dissection[28]. The ascending aorta possesses high velocity, consequent shear stress, and four-dimensional rotational and pulsatile movements during the cardiac cycle. Thus, the proximal and deep implantation of the device into zone 0 of the arch exposes the endoprosthesis to maximal hemodynamic pressure, which in turn increases the risk of malorientation as a result of the windsock effect[29]. Therefore, shorter and wider dimensions of the endoprosthesis are favoured, and 15% oversizing of the endoprosthesis relative to the native aortic diameter is recommended to improve FL depressurization and aneurysmal regression[30].

The triple-branched RELAY™ endoprosthesis allows for cannulation of the three-supra aortic vessels and is most suitable for long-term patency. Maintaining the left subclavian artery (LSA) patency after TER is paramount to circumvent the risk of left arm ischemia as well as SCI. Further, it avoids the subclavian steal syndrome and vertebrobasilar insufficiency, thus, leading to lower rates of stroke[31]. In cases where LSA cannulation is not possible, a single- or double-branched RELAY™ system is used, and prophylactic revascularization of the LSA (e.g., subclavian-carotid bypass) prior to TEVAR can be performed[32]. A study by Bradshaw *et al.* reported a 1.9% stroke rate in patients who underwent revascularization of the LSA[31]. In contrast, a stroke rate of 14.3% was reported in those who underwent TEVAR with total LSA occlusion.

Figure 1. Left: Single-branched RELAY™ endoprosthesis. Middle: Double-branched RELAY™ endoprosthesis. Right: Triple-branched RELAY™ endoprosthesis. Figure reused from Terumo Aortic website.

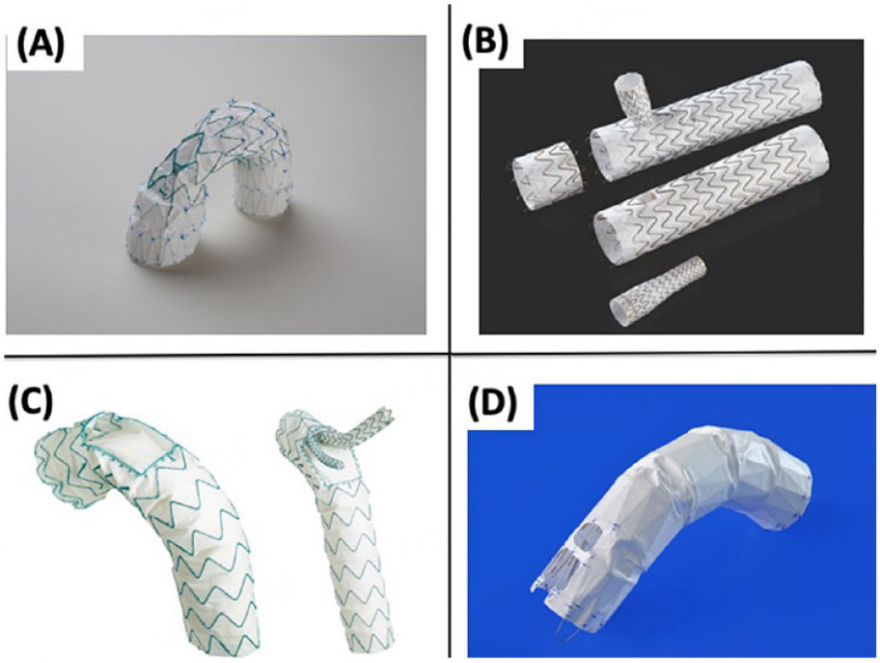

Figure 2. Examples of commercially available TER endoprostheses. (A) Zenith A-branch, (B) TAG Thoracic Branch Endoprosthesis, (C) Terumo Aortic RELAY Plus Double Branched device, and (D) Najuta. Reproduced from Fujimura *et al.*[46], no copyright permission is required (STM signatory).

Fenestrated TEVAR is another approach that has been established in treating arch pathologies while maintaining supra-aortic vessel perfusion. The Japanese Najuta™ pre-curved fenestrated stent graft is an example of fenestrated TEVAR used in TER. The Najuta™ system does not have bridging stents to fixate the fenestrations at the target-vessel ostia[33]. Another fenestrated arch endograft, the Zenith™ device from Cook Medical, uses a preloaded wire system combining a fenestration and a scallop with a covered bridging stent to fixate the fenestration to the left common carotid artery or LSA as the target vessel[34]. The distance from the femoral vessel and the curvature of the arch make the rotation of the fenestrated devices more challenging. Thus, the precision of placement requires meticulous preoperative planning and technical skills. Therefore, the arch branched devices remain more suitable for arch diseases, especially in cases of extended or complex disease[34].

Criteria for total endovascular arch repair

Despite the great potential shown by TER, OSR remains the mainstay for the treatment of aortic arch pathologies until now. Still, there are groups of patients with certain demographics and disease

characteristics who are not suitable candidates for OSR. Those high-risk patients may benefit from an alternative endovascular approach that circumvents the hazards that come with CPB and HCA[35]. The decision of whether a patient is eligible or not for OSR is usually made after multidisciplinary evaluation on an individualized basis. Some high-risk features are well-established in the literature, such as older age (≥ 75 years), which was shown to independently and significantly predict perioperative mortality and adverse events following OSR[36,37].

Besides, the use of risk prediction tools such as the American Society of Anesthesiologists (ASA) Classification and the EuroSCORE has been employed in inferring patients' risk and determining eligibility for OSR in patients with arch disease[30,38]. Spear *et al.* used a multidisciplinary evaluation and an ASA III/IV to deem patients unfit for surgery[38]. In their report, they further specified the eligibility criteria to include a negative cardiac stress test, no Class III/IV heart failure, no stroke or myocardial infarction in the last year, no significant carotid stenosis, and GFR 45 mL/min/1.73 m^2[38]. All these factors and more are considered in the risk stratification of patients with aortic arch disease. However, the breadth of aortic arch pathologies and associated comorbidities makes it hard to certainly stratify patients with high risks. Thus, a multidisciplinary evaluation remains the best approach to determining eligibility.

In patients with high-risk profiles for OSR, a set of morphological and disease features can determine patient eligibility for TER. Initially, for stable implantation of the endograft, an adequate landing zone is pre-determined based on parameters from preoperative imaging. These parameters include (i) a sealing zone within the ascending aorta (zone 0) less than 38 mm in diameter; and (ii) a sealing zone of at least 40 mm in length in the ascending aorta or the primary entry tear is not within 20 mm of the sino-tubular junction[30,38]. Table 2 highlights detailed and specific anatomic criteria as summarized by Czerny and colleagues. Figure 3 illustrates the algorithm flowchart for determining patients' eligibility for TER.

As is the case with any procedure, TEVAR is associated with a significant learning curve that is reflected in the flow of the procedure as well as patient outcomes. This is evident in the retrospective single-centre study of TEVAR by Tan *et al.*, which showed that there was a learning curve involved reflected by higher than average mean operative time, average radiation dose and mean contrast volume used during their initial experience[39].

Clinical outcomes

An appraisal of endovascular repair for aortic arch pathology requires analysis of the clinical outcomes associated therewith. Despite the minimally-invasive nature of TER providing an obvious advantage over OSR in certain cases, TER remains associated with comparable mortality rates and key complications such as technical failure, neurological injury, need for reintervention, and loss of or failure to achieve target vessel patency (TVP)[40]. These are standard metrics used to gauge the efficacy of surgical intervention on the aortic arch, and represent key challenges to the widespread adoption of TER as the gold-standard intervention for aortic arch pathologies in specific patient groups.

Technical success and target vessel patency

In the context of TER for aortic arch pathology, technical success can be defined as successful endovascular stabilisation of the aortic arch and the subsequent maintenance of aortic arch (as well as arch vessel) patency during follow-up[40]. Singh *et al.*, in their evaluation of the RELAY™ Branched endoprosthesis in 148 patients undergoing TER between January 2019 and January 2022, reported a 99.3% (n = 147) success rate[40]. TVP was achieved in all patients and maintained during the initial 30 days postoperative. After 24 months of follow-up, an overall of 118 patients (80.2%) exhibited TVP. This included 80 (74%) patients in

Table 2. Anatomical requirements for TER as reported by Czerny *et al.*[30]

Anatomical requirements	N
Ascending aorta landing zone diameter (mm)	29-43
Distal landing zone diameter (mm)	19-43
BCT and LCCA diameter (mm)	7-20
ST junction to BCT length (mm)	> 65 or > 85
Distal landing zone length (mm)	25-30
BCT landing zone length (mm)	25
LCCA landing zone length (mm)	30
Proximal BCT to distal LCCA (mm)	< 45

BCT: Brachiocephalic trunk; LCCA: left common carotid artery; ST: sinotubular.

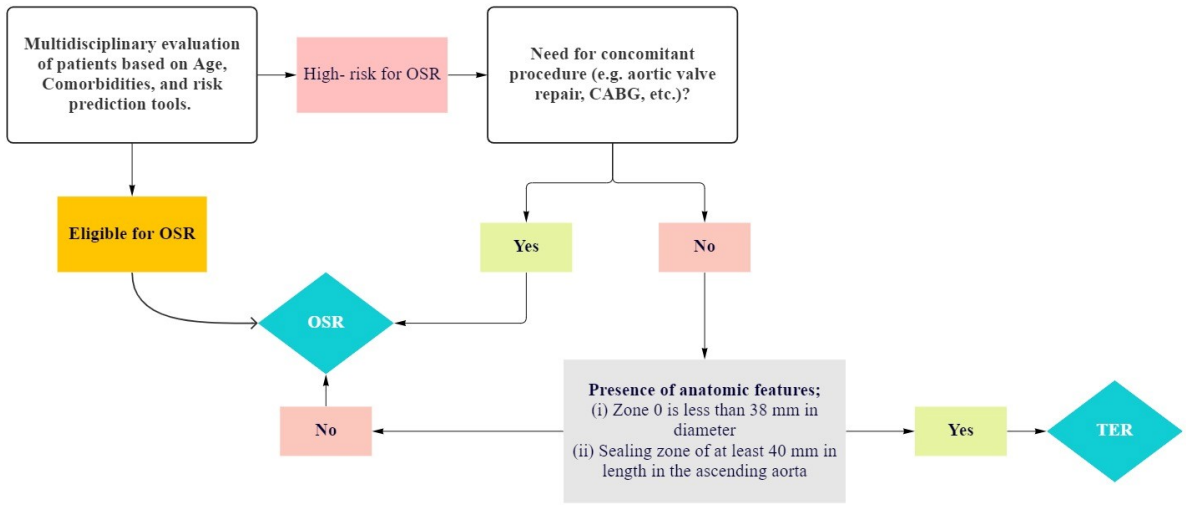

Figure 3. Flowchart (original) illustrating criteria for patients' eligibility for TER. OSR: Open surgical repair; CABG: coronary artery bypass grafting; TER: total endoarch repair.

the double-branched group and 16 (93.7%) patients in the single-branched group who exhibited TVP at 24 months postoperatively. 100% (n = 23) of patients in the triple-branched group maintained TVP during follow-up[40]. Alsafi *et al.* also report a 100% technical success rate in their smaller study of 21 patients undergoing TER with RELAY™ Branched[41].

Azuma and colleagues report a 99.2% technical success rate in their cohort of 393 patients undergoing TER with the fenestrated Kawasumi Najuta™ endograft[42]. Sato *et al.* similarly report technical success in 97.3% of patients treated with the Najuta™ device[43]. The proximal landing zone was in Zone 0 for 86.1% of patients, while Zone 1 was selected in 13.9% of patients[43]. Iwakoshi *et al.* report a 91% success rate in their series of 32 patients undergoing TER with Najuta™[44]. Spear *et al.* report a very promising 100% technical success rate in their series of 27 patients treated with the Cook Zenith™ endoprosthesis[38]. The nonrandomized, single-arm prospective study of 9 patients who underwent TER using the Valiant™ endoprosthesis by Roselli *et al.* reported a 100% technical success rate[45].

Fujimura *et al.* highlight that TER with GORE TAG™ Thoracic Branched Endoprosthesis was anatomically feasible in 40.8% (n = 87) of patients, while TER with Relay™, Najuta™, and Zenith™ was only anatomically

feasible in 24.9%, 13.6%, and 5.2% of cases respectively[46]. They suggest that TER was only feasible in 5% to 41% of patients in their series of 213 patients with arch aneurysms using fenestrated or branched endoprostheses[46]. A summary of the findings in the above subsection can be found in Table 3.

Mortality

Having traded median sternotomy for peripheral arterial cannulation, and hypothermic circulatory arrest and cardiopulmonary bypass for simple general anaesthesia, TER is associated with improved early and long-term mortality rates relative to OSR[40,41].

Singh *et al.* report a 30-day mortality rate of 2.7% (n = 4) but 0 mortalities during the remainder of their follow-up period[40]. In contrast, Alsafi *et al.* report a 9.5% (n = 2) in-hospital mortality rate in their cohort of 21[41]. The RESTORE I and II trials were published earlier, reporting on different configurations of the RELAY™ device indicated for various aortic pathologies. The RESTORE I trial reported an in-hospital mortality of 7.2% (n = 19). This rate went lower in the RESTOE II trial featuring in-hospital mortality of 4% (n = 7)[47,48]. Additionally, Azuma *et al.* revealed a 1.5% (n = 6) 30-day mortality rate associated with Najuta™, while Sato *et al.* reported a 0% in-hospital mortality rate[42,43]. However, four deaths occurred during follow-up due to malignancy and retrograde type A aortic dissection[43]. Spear *et al.* report a promising 0% mortality rate associated with Zenith™, but a 3.7% 1-year aortic-related mortality[38]. O'Callaghan *et al.* highlight a 7% (n = 1) in-hospital mortality in patients who underwent TER with custom Cook Zenith™ and 18% (n = 3) in patients who received the non-custom endoprosthesis for proximal thoracic aneurysms[49]. Interestingly, Roselli *et al.* found no mortalities using the Valiant™ endoprosthesis[45]. A summary of the findings in the above subsection can be found in Table 4.

Neurological injury

Neurological injury in the setting of aortic arch repair results primarily from ischaemia. The aetiology of cerebral injury in the context of endovascular arch repair is usually embolisation of endoluminal particulate matter (e.g., atheromatous plaque) during endovascular manipulation, or inadvertent occlusion of the carotid arteries by endovascular instrumentation[45,50]. Furthermore, spinal cord injury often occurs secondary to intercostal artery coverage by the endograft leading to compromised perfusion[51]. There is also a risk of vertebrobasilar insufficiency in patients that undergo total endovascular arch repair where the left subclavian artery is occluded and not revascularized[52].

Alsafi *et al.* report a 14% (n = 3) and 5% (n = 1) incidence of stroke and paraplegia following implantation of Relay™ Branched for TER[41]. Tan *et al.* also used Relay™ Branched in their study of 148 patients[53], which yielded a 4.1% (n = 6) stroke rate. The RESTORE I trial found that the incidence of stroke and paraplegia was 1.6% (n = 5) and 2% (n = 6), respectively, while this was 0.6% and 2.9% in RESTORE II. Azuma *et al.* noted that 1.8% (n = 7) of patients undergoing TER with Najuta™ suffered postoperative stroke and 0.8% (n = 3) paraplegia[42]. Using the same endograft, Sato *et al.* found that 16.7% (n = 6) of patients implanted with Najuta™ suffered a postoperative stroke[43], while 2.8% (n = 1) suffered postoperative paraplegia. Similarly, Iwakoshi *et al.* highlight 1 case (3.1%) of cerebral infarct and 1 case (3.1%) of spinal cord injury (SCI) following TER with Najuta™[44]. Using Zenith™, O'Callaghan *et al.* report a total of 2 (6%) cases of postoperative cerebrovascular accident and 2 (6%) of SCI[49]. Similarly, Spear *et al.* found 2 (7.4%) cases each of postoperative stroke and SCI following TER with Zenith™[38]. Finally, none of the 9 patients in the Valiant™ endoprosthesis study by Roselli *et al.* experienced major strokes perioperatively[45]. A summary of the findings in the above subsection can be found in Table 5.

Table 3. Summary of the technical success and target vessel patency subsection findings

Study	Device	Cohort size	Technical success rate (%)
Singh *et al.*[40]	RELAY™	148	99.3
Alsafi *et al.*[41]	RELAY™	21	100
RESTORE I[47]	RELAY™	307	97.7
RESTORE II[48]	RELAY™	173	97.1
Azuma *et al.*[42]	Najuta™	393	99.2
Sato *et al.*[43]	Najuta™	37	97.3
Iwakoshi *et al.*[44]	Najuta™	32	91
Spear *et al.*[38]	Cook Zenith™	27	100
Roselli *et al.*[45]	Valiant™	9	100

Table 4. Summary of the mortality subsection findings

Study	Device	Cohort size	Early mortality	Mean follow-up period and mortality rate	
				Follow-up	Overall Mortality
Singh *et al.*[40]	RELAY™	148	2.7% (*n* = 4)	2 years	2.7% (*n* = 4)
Alsafi *et al.*[41]	RELAY™	21	9.5% (*n* = 2)	36 (3-183) weeks	19% (*n* = 4)
RESTORE I[47]	RELAY™	307	7.2% (*n* = 19)	-	
RESTORE II[48]	RELAY™	173	4.0% (*n* = 7)	2 years	6.4% (*n* = 11)
Azuma *et al.*[42]	Najuta™	393	1.5% (*n* = 6)	-	
Sato *et al.*[43]	Najuta™	37	0%	2.9 ± 2.9 years	11.1% (*n* = 4)
Spear *et al.*[38]	Cook Zenith™	27	0%	1 year	3.7% (*n* = 1)
O'Callaghan *et al.*[49]	Cook Zenith™ Custom	15	7% (*n* = 1)	-	
	Cook Zenith™ Non-Custom	18	18% (*n* = 3)		

Table 5. Summary of the neurological injury subsection findings

Study	Device	Cohort size	Stroke (%)	Paraplegia (%)	SCI (%)
Alsafi *et al.*[41]	RELAY™	21	14	5	-
Tan *et al.*[54]	RELAY™	148	4.1	-	-
RESTORE I[47]	RELAY™	307	1.6	2	-
RESTORE II[48]	RELAY™	173	0.6	2.9	-
Azuma *et al.*[42]	Najuta™	393	1.8	0.8	-
Sato *et al.*[43]	Najuta™	37	16.7	2.8	-
Iwakoshi *et al.*[44]	Najuta™	32	3.1	-	3.1
O'Callaghan *et al.*[49]	Cook Zenith™	33	6	-	6
Spear *et al.*[38]	Cook Zenith™	27	7.4	-	7.4
Roselli *et al.*[45]	Valient™	9	0	-	-

Reintervention

The need for reintervention is a well-known aspect of endovascular aortic repair, especially in comparison to OSR. Reintervention is typically indicated in cases involving postoperative retrograde dissection, endoleak, or endograft migration[40]. Type 1a endoleak, in particular, is suggestive of suboptimal proximal or distal sealing, or graft migration, and is therefore a familiar complication in the context of endovascular arch repair[40].

Table 6. Summary of the reintervention subsection findings

Study	Device	Cohort size	Reintervention (%)
Singh *et al.*[40]	Single- or -triple-branched RELAY™	40	0
	Double-branched RELAY™	108	16.2
Alsafi *et al.*[41]	RELAY™	21	10
RESTORE[47]	RELAY™	307	0.7
RESTORE II[48]	RELAY™	173	Early: 3.5
			Late: 7.5
Azuma *et al.*[42]	Najuta™	393	0.8
Sato *et al.*[43]	Najuta™	37	8.3
Iwakoshi *et al.*[44]	Najuta™	32	12.5
Spear *et al.*[38]	Cook Zenith™	27	7.4
O'Callaghan *et al.*[49]	Cook Zenith™	33	30.3
Roselli *et al.*[45]	Valiant™	9	0

None of the patients in Singh *et al.* who underwent TER using single- or triple-branched RELAY™ required reintervention, while 24 (16.2%) patients that received the double-branched RELAY™ did require this post-TER[40]. Alsafi *et al.* reported a 10% (n = 2) reintervention rate in their series due to type 2 endoleak using RELAY™[41]. Two patients enrolled in the RESTORE I trial required surgical conversion postoperatively, while in RESTORE II, the rates of early and late reintervention were 3.5% and 7.5%, respectively. Furthermore, Azuma *et al.* found a 0.8% (n = 3) rate of retrograde dissection requiring reintervention associated with Najuta™[42]. Using the same device, Sato *et al.* reported an 8.3% (n = 3) reintervention rate during the 2.9 ± 2.9 year follow-up period[43]. This value was even higher in Iwashoki *et al.* at 12.5% (n = 4)[44]. With Zenith™, and during a median follow-up period of 12 months, Spear *et al.* found that 2 (7.4%) patients developed type 1a endoleak following TER and needed secondary intervention[38]. On the contrary, but also with Zenith™, the rate of reintervention in O'Callaghan was 30.3% (n = 10). Interestingly, none of the patients in Roselli *et al.* underwent reintervention following Valiant™ implantation[45]. A summary of the findings in the above subsection can be found in Table 6.

CONCLUSION

Endoarch repair using TEVAR represents the future of aortic arch repair. While FET is associated with excellent clinical outcomes, TER has achieved highly comparable results due to its novelty. Nevertheless, further studies with larger cohorts and longer follow-up periods are necessary to solidify the evidence on TER. In addition, studies directly comparing arch OSR to TER are warranted to determine superiority.

DECLARATIONS

Authors' contributions

Devised the manuscript topic and supervised the literature search and writing process: Bashir M, Mohammed I

Performed the literature search and wrote the manuscript: Jubouri M, Al-Tawil M, Tan SZCP, Geragotellis A, Hussain M

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