European Journal of Cardio-Thoracic Surgery 2023, 63(1), ezac561
https://doi.org/10.1093/ejcts/ezac561 Advance Access publication 9 December 2022

ORIGINAL ARTICLE

Cite this article as: D'Onofrio A, Lachat M, Mangialardi N, Antonello M, Schelzig H, Chaykovska L *et al.* Three-year follow-up of aortic arch endovascular stent grafting with the Nexus device: results from a prospective multicentre study. Eur J Cardiothorac Surg 2023; doi:10.1093/ejcts/ezac561.

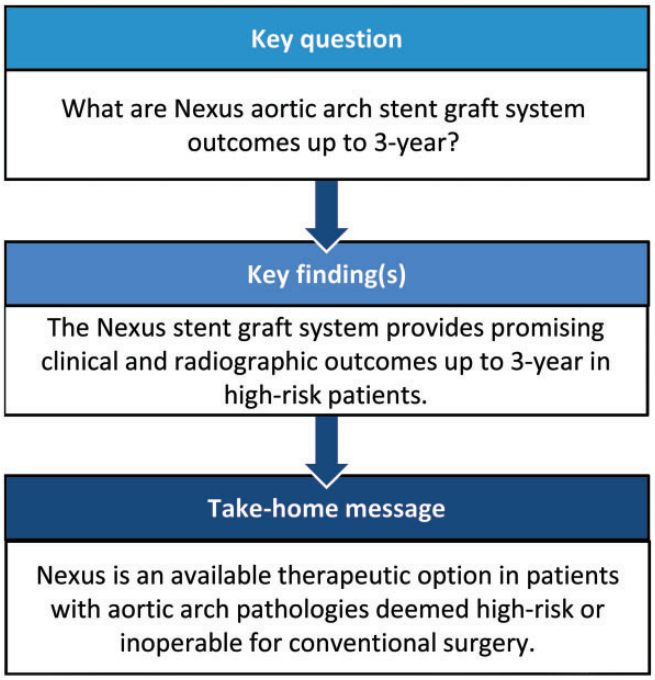
Three-year follow-up of aortic arch endovascular stent grafting with the Nexus device: results from a prospective multicentre study

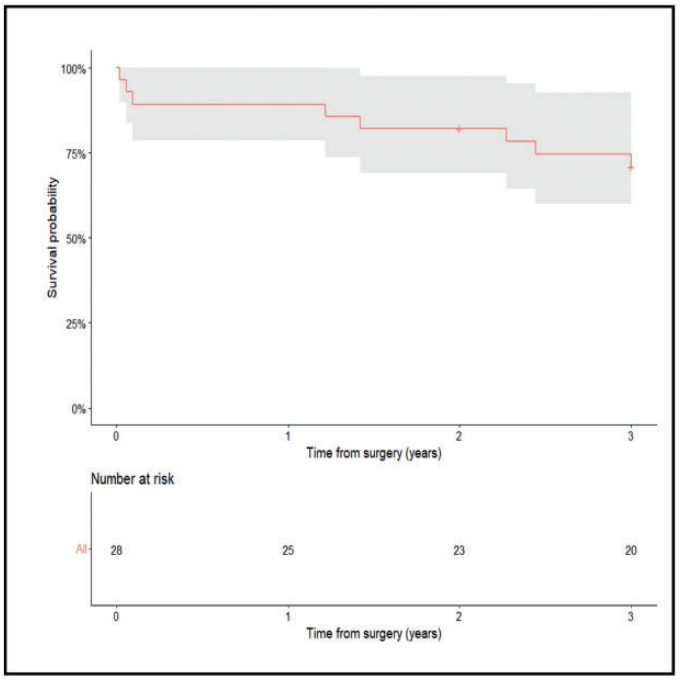
Augusto D'Onofrio [a*], Mario Lachat[b], Nicola Mangialardi[c], Michele Antonello[a], Hubert Schelzig[d], Lyubov Chaykovska[b], Andrew Hill[e], Andrew Holden[e], Thomas Lindsay[f], Kong Ten Tan[f], Matteo Orrico[c], Sonia Ronchey[g], Gabby Elbaz Greener [h], Paul Hayes[i], Giulia Lorenzoni[a], Gino Gerosa [a†] and David Planer[h†]

[a] University of Padova, Department of Cardiac, Thoracic, Vascular Surgery and Public Health, Padova, Italy
[b] Clinic Hirslanden, Aortic and Vascular Center, Zurich, Switzerland
[c] Ospedale San Camillo-Forlanini, Department of Vascular Surgery, Roma, Italy
[d] Universitätsklinik für Gefäß- und Endovaskularchirurgie, Düsseldorf, Germany
[e] Auckland Hospital, Department of Interventional Radiology, Auckland, New Zealand
[f] Toronto General Hospital, University Health Network, Department of Vascular Surgery, Toronto, ON, Canada
[g] Ospedale San Filippo Neri, Department of Vascular Surgery, Roma, Italy
[h] Hadassah—Hebrew University Medical Center, Department of Interventional Cardiology, Jerusalem, Israel
[i] St John's Innovation Centre, Department of Vascular Surgery, Cambridge, UK

* Corresponding author. University Hospital of Padua, Via Giustiniani 2, 35128 Padova, Italy. Tel:+39-0498212410-11-12-13; e-mail: adonofrio@hotmail.it (A. D'Onofrio).

Received 25 May 2022; received in revised form 5 December 2022; accepted 9 December 2022





Abstract

OBJECTIVES: Endovascular aortic arch stent grafting with branched devices has shown initial promising results. The aim of this prospective, multicentre study was to evaluate 3-year outcomes of aortic arch stent grafting with NEXUS® Aortic Arch Stent Graft System (Nexus),

†These authors contributed equally to this work.

a single-branch, bi-modular, off-the-shelf aortic arch stent graft system in high-risk patients.

METHODS: Patients treated with Nexus, either under the feasibility clinical study or as compassionate use procedures in 5 centres, were included in this study. The primary end point was overall survival. The secondary end points included the incidence of procedure-related unplanned intervention, stroke, paraplegia and endoleak. Clinical and radiologic follow-up was performed at each study site at 30 days, 6 months and on a yearly basis thereafter up to 3 years postoperatively.

RESULTS: We analysed data from a total of 28 patients. The overall median follow-up was 1132 (interquartile range: 809–1537). There were no device or procedure-related deaths between 1 and 3 years. Overall survival at 1 and 3 years was 89% and 71%, respectively. The cumulative incidence of unplanned reintervention at 1 and 3 years was 11% and 29%, respectively. There were no reports of stroke, paraplegia, aneurysm rupture, myocardial infarction or new aortic valve insufficiency. In this study's 1–3 year follow-up period, 1 type Ib (4%), 1 type II (4%) and 2 type III (8%; between Nexus' distal end and Thoracic endovascular aortic repair (TEVAR) extensions) endoleak were detected.

CONCLUSIONS: Endovascular aortic arch exclusion with the single-branch, off-the-shelf Nexus system provides promising clinical and radiologic results at 3-year follow-up in a high-risk patient cohort.

Keywords: Aortic arch • Endovascular surgery • TEVAR

ABBREVIATIONS

ASG	Aortic arch stent grafting
BCT	Brachio-cephalic trunk
EC	Ethical Committee
FET	Frozen elephant trunk

INTRODUCTION

The standard treatment for patients with aortic arch disease is represented by surgical aortic arch replacement, with or without frozen elephant trunk (FET) [1]. This procedure is technically demanding since it requires cardiopulmonary bypass, hypothermic circulatory arrest and cerebral perfusion and it is associated with a relatively high rate of stroke and mortality, especially in high-risk patients and in those with previous cardiac operations [2]. Recently, endovascular aortic arch stent grafting (ASG) with proximal landing in Ishimaru zone 0 and distal landing in zones IV–V with branched devices has been introduced into clinical practice and has shown initial promising results [3]. Endovascular aortic arch repair greatly reduces the invasiveness of the operation if compared to conventional open surgery since it is performed on the beating heart, with no sternotomy, no cardiopulmonary bypass, no circulatory arrest, brain perfusion is always maintained and with minimally invasive device access (often percutaneous). Therefore, this procedure can be considered a microinvasive approach to the aortic arch [4, 5] being particularly beneficial for high-risk patients. The aim of this prospective, multicentre study was to evaluate 3-year outcomes of ASG with a bi-modular, off-the-shelf, endovascular aortic arch system.

PATIENTS AND METHODS

Ethical statement

The study protocol was approved by each site's Ethical Committee (EC) and/or national Ministry of Health, as required by local regulations (coordinating centre EC approval number 2017-01521, 18 January 2018, Universitätsspital Zürich). All patients signed an informed consent before being included in the study. All compassionate cases were approved by the local EC and/or national Ministry of Health.

Study device

The NEXUS® Aortic Arch Stent Graft System (Nexus) (Endospan, Herzlia, Israel) is a CE-marked, off-the-shelf, single-branch, bi-modular device, specifically designed for the treatment of aortic arch pathologies that has already shown good 1-year outcomes. Nexus characteristics and implantation technique have been extensively described elsewhere [6]. Briefly, Nexus is an off-the-shelf, single-branch, bi-modular stent graft system (Fig. 1) made of nitinol and polyester. The main module is implanted from the brachio-cephalic trunk (BCT) branch to the aortic arch and the thoracic aorta; it features a side-facing dock that connects with the ascending module. The ascending module is curved, to adapt to the curved anatomy of the ascending aorta, and lands proximally at the sinotubular junction. Nexus' components come into different sizes to fit the great majority of patients. The delivery systems are precurved and 20- Fr introducer compatible. A few days before (range 1–7) Nexus implantation supra-aortic extra-anatomic bypass (right common carotid-left common carotid-left subclavian artery) is performed, although in some cases, especially during the initial experience, a parallel graft technique was used for revascularization of the supra-aortic vessels. The latter was generally performed simultaneously with the Nexus implantation. Nexus implantation was performed under general anaesthesia and with full systemic heparinization. Using an

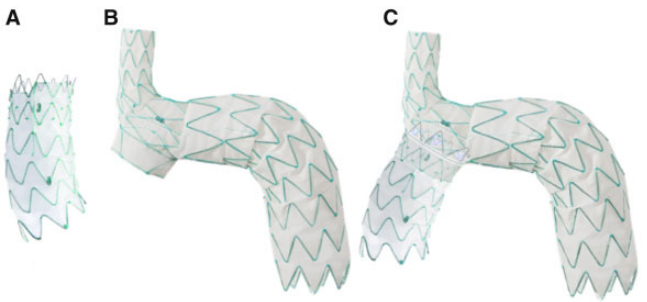
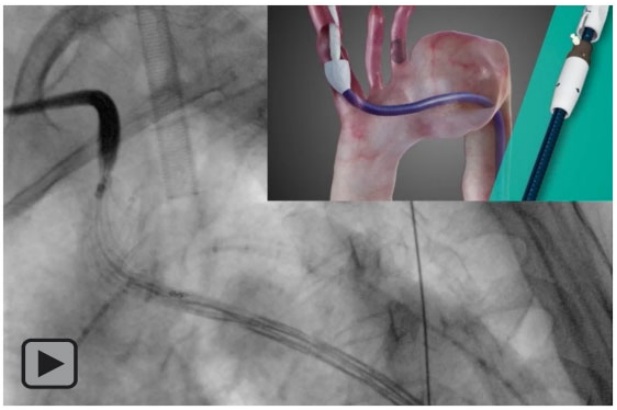


Figure 1: Nexus aortic arch system. (**A**) Ascending module; (**B**) main module; and (**C**) final assembled device. The interlocking system between the 2 modules has been made visible in transparency.



Video 1: This video shows Nexus implantation procedure. On a femoral-axillary through and through guidewire, the main module is deployed in the aortic arch with the side branch in the brachio-cephalic artery and the self-projecting sleeve well oriented towards the ascending aorta. To correctly orient the self-projecting sleeve, the device is gently pushed towards the ascending aorta during the deployment of the main module. After positioning a second guidewire in the left ventricle, the ascending module is deployed during rapid pacing. Final ballooning is performed in order to achieve optimal positioning and connection between modules. Final angiography shows a good final result with a small type 2 endoleak from the patent left subclavian artery that was plugged at the very end of the procedure. Pre-discharge CT scan showed no residual endoleaks.

axillary artery-femoral artery "through-and-through" guidewire the main module is deployed in the aortic arch with the side branch in the BCT and with the dock properly facing the ascending aorta. This segment is then ballooned under rapid pacing. Then, a precurved guidewire is placed in the left ventricle (as for transfemoral aortic valve implantation) and the ascending module is advanced until correct positioning for proper modules connection is achieved. During rapid ventricular pacing, the ascending module is deployed. Finally, dual BCT ascending moulding balloon inflation (kissing Percutaneous transluminal angioplasty (PTA) balloon) is performed under rapid pacing to optimize the stabilization of the device (Video 1).

Study population

In this study, we included patients treated with the Nexus system either under the feasibility clinical study (NCT02365454) or as compassionate use procedures (NCT03420066) in 5 centres in Europe, Canada and New Zealand. All clinical and anatomical inclusion and exclusion criteria are shown in the Supplementary Material. Briefly, inclusion criteria were aortic arch aneurysms, aortic dissections, residual aneurysm or dissection following ascending open or endovascular repair, pseudo-aneurysms and penetrating aortic ulcers, deemed to be at high risk for open surgical repair. The surgical risk was evaluated at each centre by multidisciplinary team discussion (always by cardiac and/or vascular surgeon and anaesthesiologist; when needed: radiologist, cardiologist, other specialists) based on age and clinical characteristics and medical history. Exclusion criteria were acute dissection or rupture; suspected infective aetiology; major intra-luminal plaques; untreated aneurysm or dissection of the ascending aorta or the BCT; and known connective tissue disease. All patients underwent angio-Computed tomography (CT) before the procedure to evaluate anatomical feasibility and dimensions of different aortic segments to select the most appropriate Nexus' modules sizes. All cases were discussed within the local aortic team for risk assessment and choice of the most appropriate procedure.

Study end points

The primary end point of the present study was overall survival. Secondary end points were incidence of procedure-related unplanned reintervention, stroke, paraplegia and endoleak at follow-up. The early results up to 1 year have already been published [6]; therefore, this report will focus on events occurring between 1 and 3 years. Unplanned reintervention was defined as any procedure performed to treat complications such as fixing of endoleaks, unplanned distal stenting of the thoracic aorta or infection of supra-aortic bypass graft. Furthermore, the incidence of major adverse events like myocardial infarction and new-onset aortic valve insufficiency was evaluated. All serious adverse events were recorded and adjudicated by an independent Clinical Events Committee according to the DEFINE group [7] and the Valve Academic Research Consortium-2 (VARC-2) definitions [8].

Follow-up. Clinical and imaging follow-up was performed at each study site at 30 days, 6 months and on a yearly basis thereafter up to 3 years postoperatively. Angio-CTs evaluated apposition, migration, patency, occlusion of visceral vessels, stent fracture or deformity, aneurysm rupture, aneurysm growth and endoleak type (including gutter endoleak). Images were reviewed by an independent radiologist.

Statistical analysis

Data are presented as means and standard deviations or median and interquartile range for continuous variables (as appropriate) and absolute numbers and percentages for categorical variables. Comparisons were made with Student's *t*-test, Mann–Whitney *U*-test or Fisher's exact test, as appropriate. Survival analysis used the Kaplan–Meier method, and reintervention rate was evaluated using cumulative incidence function to account for competing risks. Statistical analysis was performed using R software version 4.1.3 (www.R-project.org) within the packages survival and cmprsk.

RESULTS

A total of 28 patients were included in this study. In particular, 18 (64%) and 10 (36%) patients were included in the investigational study and in the compassionate use pathway, respectively. Principal baseline and early outcomes have already been reported [6]. Briefly, the mean age was 72 ± 6 years, 15 patients (54%) had a history of cardiac surgery and 25 patients (89%) had an American Society of Anaesthesiology score ≥3. Details for the 2 cohorts are given in Table 1. Indications for Nexus were isolated aortic arch aneurysm, chronic dissection and penetrating

Table 1: Baseline characteristics for the 2 cohorts

Variable	First in man cohort ($n = 18$)	Compassionate cohort ($n = 10$)	Entire cohort ($n = 28$)	*P*-Value
Age (years), mean + SD	72 ± 6	73 ± 7	72 ± 6	0.55
Male, *n* (%)	16/18 (89)	6/10 (60)	22/28 (79)	0.15
BMI (kg/m^2), mean + SD	29 ± 5.4	27 ± 7	28 ± 6	0.57
Arterial hypertension, *n* (%)	18/18 (100)	9/10 (90)	27/28 (96)	0.36
COPD, *n* (%)	5/18 (28)	4/10 (40)	9/28 (32)	0.68
CAD, *n* (%)	7/18 (39)	2/10 (20)	9/28 (32)	0.42
Arrhythmia, *n* (%)	6/18 (33)	1/10 (10)	7/28 (25)	0.36
Previous sternotomy, *n* (%)	12/18 (67)	3/10 (30)	15/28 (54)	0.11
CVA/TIA, *n* (%)	1/18 (6)	1/10 (10)	2/28 (7)	1.00
ASA risk score ≥3, *n* (%)	16/17 (94)	9/10 (90)	25/27 (93)	0.70

ASA: American Society of Anesthesiologists; BMI: body mass index; CAD: coronary artery disease; COPD: chronic obstructive pulmonary disease; CVA: cerebrovascular accident; SD: standard deviation; TIA: transitory ischaemic attack.

Table 2: Procedural characteristics

Variable	Median [IQR]
Total procedure time (min)[a]	185 [148–254]
Nexus procedure time (min)[b]	80 [46.5–113]
Fluoroscopy time (min)	48 [37.5–54]
Contrast volume (ml)	122.5 [102.5–187.5]
Length of hospitalization following procedure (days)	8.5 [7.0–14.7]
Number of patients admitted to ICU, *n* (%)	16/28 (57)
Length of ICU stay (days)	1.0 [1.0–3.0]
Complete percutaneous access, *n* (%)	19/28 (68)

[a]Total procedure time: skin-to-skin.

[b]Nexus procedure time: time from access with the arch stent graft delivery system until retrieval of the ascending stent graft delivery system.

ICU: intensive care unit; IQR: interquartile range.

aortic ulcer in 17 (61%), 6 (21%) and 1 (4%) patients, respectively. The remaining 4 patients (14%) were suffering from combined conditions. Nexus was successfully implanted in all cases, with operative details provided in Table 2. The overall median follow-up is 38 (interquartile range: 30–51) months, with 1 patient lost after their 2-year follow-up due to emigration. For clarity, 30-day, 1-year and 3-year outcomes are summarized in Table 3. Overall survival at 1 and 3 years was 89% and 71%, respectively (Fig. 2). Death during this medium-term follow-up period occurred in 5 patients. Importantly, there were no deaths that were device related or due to aneurysm growth or rupture. One patient died of sepsis from cholecystitis (15 months); 1 patient died of worsening cardiorenal syndrome (17 months); 1 patient died of stroke complications attributed to atrial fibrillation (24 months); 1 patient died of pneumonia/chronic obstructive pulmonary disease exacerbation (29 months); and 1 patient died of COVID-19 pneumonia (36 months).

During years 1–3, no patient required open aortic surgical reintervention. Two patients required Thoracic endovascular aortic repair (TEVAR) extensions for distal disease progression and 1 Left subclavian artery (LSA) stent was re-lined. Cumulative incidence of device or procedure-related unplanned reintervention was 11% and 29% at 1 and 3 years, respectively (Fig. 3). In the current follow-up period, 2 patients underwent open surgery for cervical bypass graft infections (autologous vein reconstruction).

No strokes occurred during follow-up except for 1 TIA that happened 1 year after the procedure with symptoms that completely resolved within 24 h and no CT signs of brain infarction nor haemorrhage. During follow-up, there were no reports of paraplegia, myocardial infarction or new aortic valve insufficiency. Likewise, reports of type-Ia, -IV and -V endoleaks were absent. A single type-Ib endoleak developed after 2 years due to proximal migration of the distal end of an extension thoracic aortic stent. There were no type III endoleaks between the 2 Nexus components. We observed 2 new type-III endoleaks between the distal end of Nexus and TEVAR extensions into the distal aorta; 1 was successfully treated with TEVAR and the second was under clinical follow-up at 3 years. One asymptomatic Right common carotid (RCC)–Left common carotid (LCC) bypass occlusion was detected on scanning that did not require intervention. During the follow-up period, aneurysm expansion (>5 mm from baseline scan) occurred in 1 patient that is currently under surveillance.

DISCUSSION

The main findings of the present study are that ASG using the Nexus devices provides excellent 3-year outcomes in terms of overall survival, aortic-related death, paraplegia, unplanned reoperation, stroke and endoleaks. Although conventional open surgery is currently considered to be the treatment of choice in patients with aortic arch pathology, it carries a relatively high rate of mortality and postoperative complications, especially in elderly and/or high-risk patients [2]. In this subset of patients, a microinvasive procedure [5], performed on the beating heart, with no bypass/circulatory arrest might reduce the surgical impact. Although we do not have a surgical group for direct comparison, early mortality (11%), 3-year survival (71%) and unplanned reoperation rate (11% at 1 year and 29% at 3 years) reported in this experience do not seem different from data present in the literature for open arch surgery, especially taking into consideration the preoperative characteristics. It is worth noting that our current study population also included 10 (36%) compassionate use patients, who had a mean age of 72 years, 32% were suffering from chronic obstructive pulmonary disease and 53% had already undergone open heart surgery. Their ASA risk score was ≥3 in 94%, thus reflecting a high-risk cohort. Shrestha *et al.* report a mortality rate of 7% and a 3-year survival of 81% in 100 patients undergoing FET with a mean age of 59 years.

Table 3: Patient safety, performance and endoleaks events as an incidence over 3 years, with a cumulative total

	0–30 days (*n* = 28)	31 days to 1 year (*n* = 26)	1–3 years (*n* = 25)	Total (*n* = 28)
Safety, *n* (%)				
Overall mortality	2 (7)	1 (4)	5 (20)	8 (29)
Device-related mortality	0	0	0	0
Procedure-related mortality	2 (7)	1 (4)	0	3 (11)
Postop aneurysm-related mortality	0	0	0	0
Any stroke	2 (7)	0	0	2 (7)
Disabling stroke	1 (4)	0	0	1 (4)
Renal failure (new onset, requiring dialysis)	1 (4)	0	0	1 (4)
Paraplegia	0	0	0	0
Myocardial infarction	0	0	0	0
Aortic insufficiency	0	0	0	0
Unplanned procedure or device-related reintervention	2 (7)	1 (4)	5 (20)	8 (29)
Aortic or Nexus-related reintervention		1 (4)	2 (8)	3 (11)
Performance, *n* (%)				
Aneurysm enlargement >5 mm	0	3 (12)	2 (8)	5 (18)
Stent graft migration	0	0	1 (4)	1 (4)
Onset of a dissection or extension of existing dissection	0	1 (4)	0	1 (4)
Aneurysm rupture	0	0	0	0
Occlusion of Nexus branch	0	0	0	0
Occlusion of cervical bypass[a]	0	1 (4)	1 (4)	2 (7)
New endoleak onset, *n* (%)				
Type Ia	0	0	0	0
Type Ib	0	0	1 (4)	1 (4)
Type II	0	4 (16)	1 (4)	5 (18)
Type III[b]	1 (4)	0	0	1 (4)
Type III[c]	0	1 (4)	2 (8)	3 (11)
Type IV/V	0	0	0	0
Undetermined	0	1 (4)	0	1 (4)

[a]Both asymptomatic.
[b]Between the 2 sections of Nexus stent grafts.
[c]Between the distal end of the Nexus and TEVAR extension.

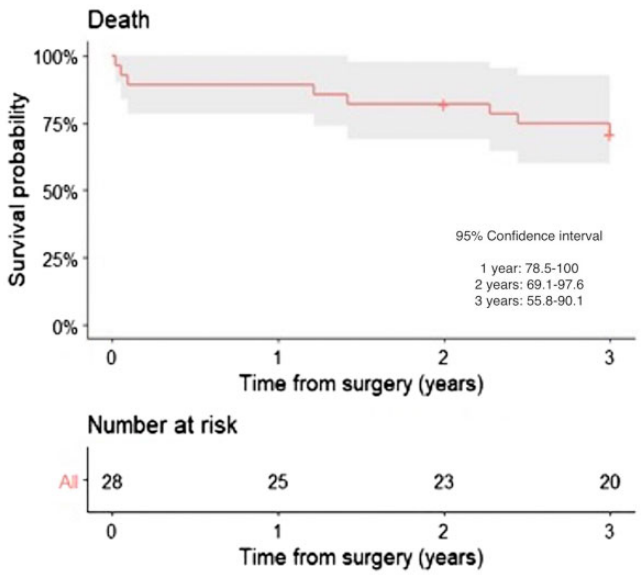


Figure 2: Kaplan–Meier 3-year overall survival analysis after Nexus implantation.

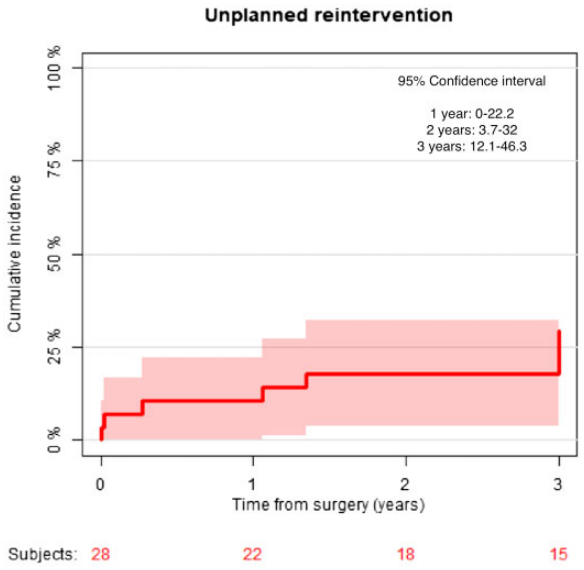


Figure 3: Cumulative incidence of procedure-related unplanned reintervention at 3-year after Nexus implantation.

Furthermore, they report an incidence of aortic reoperation of 22% overall and as high as 31% in chronic aneurysms [9]. Furthermore, Leontyev *et al.* [10] describe 5-year survival of 60% in a cohort of 51 consecutive patients undergoing FET with a mean age of 69 years. The main advantages of the Nexus device are related to its bi-modular design and its off-the-shelf

availability (relative to other arch endografts that require custom manufacturing). The bi-modular design allows surgeons to extend their repair proximally into the ascending aorta and to optimize sizing in each of the treated aortic segments. Furthermore, the strong connection between the 2 modules due to the interaction between the locking latches and the docking ring makes the occurrence of type III endoleak unlikely. In the overall experience, we observed only a single intra-Nexus type III leak, which then resolved spontaneously within the first 6 months. There were 3 endoleaks between the distal end of the Nexus and TEVAR extensions. A similar incidence of type III endoleak is reported in the literature [11, 12]. In particular, Appoo describes that type III accounted for 17% of all endoleaks in a series of 99 patients undergoing TEVAR.

One of the major concerns of endovascular repair of the aortic arch is the incidence of stroke that has been reported to be as high as 26% in multi-branch devices [13–15]. A recent series from Japan demonstrated significantly ($P < 0.01$) higher stroke rates when the device landing zone was in zone 0 compared to zone 1 or 2, and this was confirmed in a 2022 analysis of Vascular Surgery Quality Initiative date that showed an 8.4% stroke rate for innominate artery revascularization [16]. In our series where all devices landed in the highest risk zone 0, no late events were reported, and the cumulative incidence across the study was 7%. It is important to note that clinical stroke only represents the tip of the iceberg with regard to the burden of cerebral infarction occurring during TEVAR. Up to 80% of patients show signs of ischaemia damage post-arch TEVAR, and the burden is higher with more proximal disease [17]. It would seem pertinent to consider this when considering the choice of device and its mode of implantation for the treatment of degenerative arch pathology. Of note, there are no studies comparing open surgery versus ASG and also no studies comparing single-branch ASG versus double-branch ASG in terms of stroke. For open surgical procedures, paraplegia remains one of the most feared complications and despite improvements in technique, it continues to be reported. In this endovascular series, no spinal cord ischaemia was noted, either temporary or permanent, thus confirming a good safety profile. In these patients, cerebrospinal fluid drainage was never used since the procedure involved the arch with limited extension into the distal descending aorta. If distal stent grafting is planned, cerebrospinal fluid drainage should be considered in every TEVAR procedure.

The off-the-shelf availability offers the ability to implant Nexus also in urgent/emergency cases [18] when an endovascular treatment is indicated, but there is no time to wait for the manufacturing of a custom-made device that usually takes 2 and 3 months for delivery. The single-branch design has advantages and disadvantages. The main drawback when compared to double-branch devices is related to the need for a cervical bypasses (Right common carotid artery (RCCA)–Left common carotid artery (LCCA)–LSA) that is usually performed some days in advance than the endovascular procedure. These bypasses have a minimal physiological impact on the patient and can safely and easily be undertaken in the vast majority of patients. In addition, the patency rate for these surgical bypasses has been reported to be >95% at 3-year follow-up [19] and this is also confirmed by our data. On the other hand, the single-branch design makes Nexus with a femoro-axillary wire relatively easy to implant compared to other complex multi-branch endografts. Furthermore, the antegrade placement of the single side branch minimizes endovascular manipulation as well as retrograde navigation of supra-aortic vessels. All these features are particularly relevant in patients with a history of surgery for type A acute aortic dissection since they often do not have all supra-aortic vessels suitable for stent graft positioning and for retrograde navigation.

Limitations

The limitations of this study are mainly related to the small number of patients included. However, the completeness of clinical and radiologic follow-up and the presence of an independent Clinical Events Committee and of an independent radiology for CT evaluation make these results a reliable evaluation of 3-year behaviour of this device.

CONCLUSIONS

In conclusion, our data show that endovascular aortic arch exclusion with the single-branch, off-the-shelf Nexus system provides promising clinical and radiologic results at 3-year follow-up in this group of high-risk patients. Further evaluation in larger cohorts is needed to confirm these results.

SUPPLEMENTARY MATERIAL

Supplementary material is available at *EJCTS* online.

Funding

Funding for this study was provided by Endospan Ltd.

Conflict of interest: Augusto D'Onofrio received travel grants from Endospan for attending Nexus investigator meetings and Nexus implanter forums. Mario Lachat reports being a principal investigator for the clinical studies reported in this article, receiving fees as a consultant and proctor for Endospan since 2014 and CryoLife since 2019, as well as being a medical director for Endospan and holder of stock options since 2019. David Planer reports being a consultant and a proctor for Endospan and holder of stock options since 2019. Paul Hayes is a consultant for Endospan. Andrew Holden is a scientific advisory board member for Gore, Boston Scientific, Medtronic and Philips. Thomas Lindsay received travel reimbursement from Endospan and is a proctor for Cook. Sonia Ronchey is a proctor for Terumo. The remaining authors report no disclosures.

Data availability

The data underlying this article will be shared on reasonable request to the corresponding author.

Author contributions

Augusto D'Onofrio: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Resources; Supervision; Validation; Visualization; Writing—original draft; Writing—review & editing.

Mario Lachat: Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Resources; Supervision; Validation; Writing—original draft; Writing—review & editing. **Nicola Mangialardi:** Conceptualization; Data curation; Investigation; Methodology; Validation; Writing—review & editing. **Michele Antonello:** Conceptualization; Data curation; Investigation; Methodology; Supervision; Validation; Writing—original draft; Writing—review & editing. **Hubert Schelzig:** Conceptualization; Data curation; Investigation; Methodology; Validation; Writing—review & editing. **Lyubov Chaykovska:** Conceptualization; Data curation; Investigation; Visualization; Writing—review & editing. **Andrew Hill:** Conceptualization; Data curation; Investigation; Methodology; Validation; Writing—review & editing. **Andrew Holden:** Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Supervision; Writing—review & editing. **Thomas Lindsay:** Conceptualization; Data curation; Investigation; Methodology; Validation; Writing—review & editing. **Kong Ten Tan:** Data curation; Investigation; Methodology; Writing—review & editing. **Matteo Orrico:** Conceptualization; Investigation; Methodology; Validation; Writing—review & editing. **Sonia Ronchey:** Data curation; Investigation; Methodology; Validation; Writing—review& editing. **Gabby Elbaz Greener:** Conceptualization; Data curation; Investigation; Methodology; Validation; Writing—review & editing. **Paul Hayes:** Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Supervision; Validation; Writing—original draft; Writing—review & editing. **Giulia Lorenzoni:** Data curation; Formal analysis; Methodology; Software; Validation; Writing—original draft; Writing—review & editing. **Gino Gerosa:** Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Resources; Supervision; Validation; Writing—original draft. **David Planer:** Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Resources; Supervision; Validation; Visualization; Writing—original draft; Writing—review & editing.

Reviewer information

European Journal of Cardio-Thoracic Surgery thanks Stoyan Kondov, Mario Lescan, David Schibilsky and the other, anonymous reviewer(s) for their contribution to the peer review process of this article.

REFERENCES

[1] Shrestha M, Bachet J, Bavaria J, Carrel TP, De Paulis R, Di Bartolomeo R *et al.* Current status and recommendations for use of the frozen elephant trunk technique: a position paper by the Vascular Domain of EACTS. Eur J Cardiothorac Surg 2015;47:759–69.

[2] Martens A, Beckmann E, Kaufeld T, Umminger J, Fleissner F, Koigeldiyev N *et al.* Total aortic arch repair: risk factor analysis and follow-up in 199 patients. Eur J Cardiothorac Surg 2016;50:940–8.

[3] Brown JA, Arnaoutakis GJ, Szeto WY, Serna-Gallegos D, Sultan I. Endovascular repair of the aortic arch: state of the art. J Card Surg 2021; 36:4292–300.

[4] D'Onofrio A, Gerosa G. Technique versus technology and the (r)evolution of cardiac surgery: a professional journey from classical surgery to embracing intervention. Eur J Cardiothorac Surg 2017;52:835–7.

[5] Gerosa G, Thourani VH, Borger M, D'Onofrio A. Microinvasive cardiac surgery: when less is more-'render to Caesar the things that are Caesar's; and to the surgeon the things that are the surgeons. Eur J Cardiothorac Surg 2022;14:ezac084.

[6] Planer D, Elbaz-Greener G, Mangialardi N, Lindsay T, D'Onofrio A, Schelzig H *et al.* NEXUS Arch: a multicenter study evaluating the initial experience with a novel aortic arch stent graft system. Ann Surg 2021. doi:10.1097/SLA.0000000000004843.

[7] Diehm N, Vermassen F, van Sambeek MR; DEFINE Investigators Standardized definitions and clinical endpoints in trials investigating endovascular repair of aortic dissections. Eur J Vasc Endovasc Surg 2013; 46:645–50.

[8] Kappetein AP, Head SJ, Genereux P, Piazza N, van Mieghem NM, Blackstone EH *et al.*; Valve Academic Research Consortium-2. Updated standardized endpoint definitions for transcatheter aortic valve implantation: the Valve Academic Research Consortium-2 consensus document. J Thorac Cardiovasc Surg 2013;145:6–23.

[9] Shrestha M, Kaufeld T, Beckmann E, Fleissner F, Umminger J, Abd Alhadi F *et al.* Total aortic arch replacement with a novel 4-branched frozen elephant trunk prosthesis: single-center results of the first 100 patients. J Thorac Cardiovasc Surg 2016;152:148–159.e1.

[10] Leontyev S, Misfeld M, Daviewala P, Borger MA, Etz CD, Belaev S *et al.* Early- and medium-term results after aortic arch replacement with frozen elephant trunk techniques. Ann Cardiothorac Surg 2013;2:606–11.

[11] Appoo JJ, Moser WG, Fairman RM, Cornelius KF, Pochettino A, Woo EY *et al.* Thoracic aortic stent grafting: improving results with newer generation investigational devices. J Thorac Cardiovasc Surg 2006;131: 1087–94.

[12] Uehara K, Inoue T, Matsuo J, Sasaki H, Matsuda H. Type IIIB endoleak from stent suture lines of a thoracic endograft. J Vasc Surg Cases Innov Tech 2019;5:214–7.

[13] Ferrer C, Cao P, Coscarella C, Ferri M, Lovato L, Camparini S *et al.*; TRIUmPH Registry Investigators. iTalian RegIstry of doUble inner branch stent graft for arch PatHology (the TRIUmPH Registry). J Vasc Surg 2019; 70:672–82.e1.

[14] Czerny M, Berger T, Kondov S, Siepe M, Saint Lebes B, Mokrane F *et al.* Results of endovascular aortic arch repair using the Relay Branch system. Eur J Cardiothorac Surg 2021;60:662–8.

[15] Spear R, Haulon S, Ohki T, Tsilimparis N, Kanaoka Y, Milne CP *et al.* Editor's choice—subsequent results for arch aneurysm repair with inner branched endografts. Eur J Vasc Endovasc Surg 2016;51:380–5.

[16] Li RD, Chia MC, Eskandari MK. Thoracic endovascular aortic repair with supra-aortic trunk revascularization is associated with increased risk of periprocedural ischemic stroke. Ann Vasc Surg 2022;87:205–12. doi: 10.1016/j.avsg.2022.06.004.

[17] Perera AH, Rudarakanchana N, Monzon L, Bicknell CD, Modarai B, Kirmi O *et al.* Cerebral embolization, silent cerebral infarction and neurocognitive decline after thoracic endovascular aortic repair. Br J Surg 2018;105:366–78.

[18] Cibin G, D'Onofrio A, Antonello M, Battocchio P, Gerosa G. Emergency endovascular total arch exclusion with an off-the-shelf bimodular device. Innovations (Phila) 2022;17:64–6. doi:10.1177/15569845211050388.

[19] Gombert A, van Issum L, Barbati ME, Grommes J, Keszei A, Kotelis D *et al.* Extra-thoracic supra-aortic bypass surgery is safe in thoracic endovascular aortic repair and arterial occlusive disease treatment. Eur J Vasc Endovasc Surg 2018;55:861–6.