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**ORIGINAL ARTICLE**

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# Results of endovascular aortic arch repair using the Relay Branch system

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**Key question**

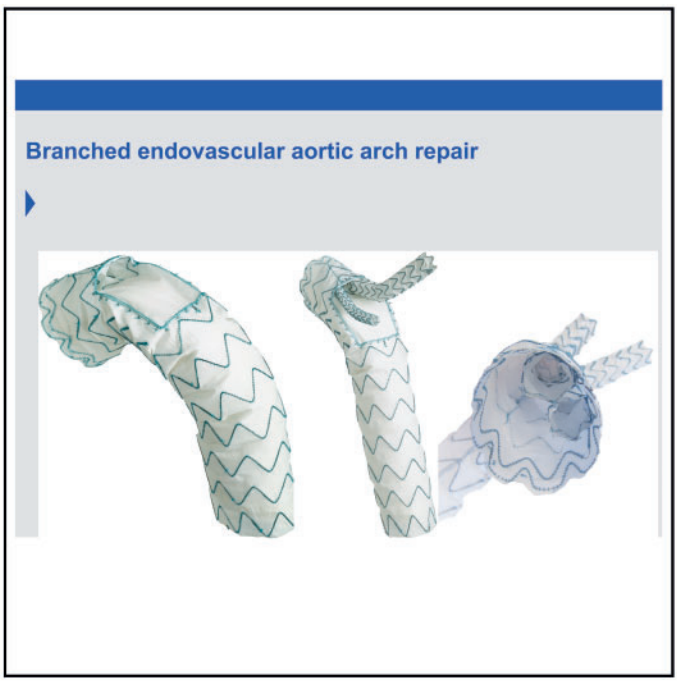
How does the Relay Branch system perform for endovascular aortic arch repair?

**Key finding(s)**

Technical success is high; mortality is acceptable; stroke remains an issue.

**Take-home message**

The technique is reliable but further studies are needed.



## Abstract

**OBJECTIVES:** Our goal was to evaluate results of endovascular aortic arch repair using the Relay Branch system.

**METHODS:** Forty-three patients with thoracic aortic pathology involving the aortic arch have been treated with the Relay Branch system (Terumo Aortic, Sunrise, FL, USA) in 10 centres. We assessed in-hospital mortality, neurological injury, treatment success according to current reporting standards and the need for secondary interventions. In addition, outcome was analysed according to the underlying pathology: non-dissective disease versus residual aortic dissection (RAD) (defined as remaining dissection after previous type A repair, chronic type B aortic dissections).

**RESULTS:** In-hospital mortality was 9% (0% in patients with RAD). Disabling stroke occurred in 7% (0% in patients with RAD); non-disabling stroke occurred in 19% (7% in patients with RAD). Early type IA and B endoleak formation occurred in 4%. Median follow-up was 16 ± 18 months. During the follow-up period, 23% of the patients died. Aortic-related deaths were low (3% in patients with RAD).

**CONCLUSIONS:** The results of endovascular aortic arch repair using the Relay Branch system in a selected patient population with regard to technical success are good. In-hospital mortality is acceptable, the number of disabling strokes is low and technical success is high. Non-disabling stroke is a major concern, and every effort has to be taken to reduce this to a minimum. The best outcome is seen in patients with underlying RAD. Finally, more data are needed.

**Keywords:** Aortic arch • Thoracic endovascular aortic repair • Endovascular aortic repair

**ABBREVIATIONS**

| | |
|---|---|
| BCT | Brachiocephalic trunk |
| LCCA | Left common carotid artery |
| LSA | Left subclavian artery |
| PAU | Penetrating atherosclerotic ulceration |
| RAD | Residual aortic dissection |

## INTRODUCTION

Thoracic aortic pathology involving the aortic arch to various extents has become a frequently diagnosed disease [1]. Treatment strategies have emerged and, depending on patient- and disease-specific factors, open surgery, combined with vascular and endovascular procedures, and approaches using branched technology are available for individualized solutions [2–5]. Whereas the results from open surgery and from combined vascular and endovascular approaches are robust, few data are available concerning branched endovascular aortic arch repair [6–8]. The reasons are mostly related to applicability because of the anatomical challenges and the still limited availability of the technology.

The goal of this study was to evaluate the results of endovascular aortic arch repair using the Relay Branch system.

## PATIENTS AND METHODS

### Patients

The study was approved by the ethical committee of the Albert Ludwigs University of Freiburg (EK 120/20). Forty-three patients with thoracic aortic pathology involving the aortic arch were treated with the Relay Branch system (Terumo Aortic, Sunrise, FL, USA) in 10 centres between March 2013 and September 2019. Retrospectively, in-hospital deaths, neurological injury, treatment success according to current reporting standards and the need for secondary interventions were assessed [9]. In addition, outcome was analysed according to the underlying pathology: non-dissective disease versus residual aortic dissection (RAD) (remaining dissection after previous type A repair, chronic type B aortic dissections).

### Anatomical requirements and patient selection

The anatomical requirements for the Relay Branch approach are an ascending aortic diameter between 29 and 43 mm; ascending aortic length from the sinotubular junction to the offspring of the brachiocephalic trunk (BCT) of at least 6.5 cm; regular diameters of the BCT and the left common carotid artery (LCCA) where the minimum diameter of the LCCA is 7 mm for insertion of the supra-aortic extension. The approach is discouraged in patients with remaining dissection of the supra-aortic vessels after previous type A repair. Currently, all devices are custom-made. Table 1 shows the anatomical requirements of both the thoracic aorta and the supra-aortic branches. All arch types are basically suitable.

### Prosthetic design

The prosthesis is designed as a modular system with retrograde delivery of the main body from the femoral or iliac axis. The main body has a large window hosting 2 internal tunnels for secondary connection of the supra-aortic extensions to the BCT (posterior tunnel) and to the LCCA (anterior tunnel). Recommended oversizing for this kind of procedure is 15% at each landing zone

**Table 1:** Anatomical requirements

| Anatomical requirements | *X* |
|---|---|
| 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.

ENDOVASCULAR AORTIC SURGERY

(ascending aorta, BCT, LCCA as well as the descending aorta). The exceptions are patients with post dissection aneurysmal formation in whom distal sizing is done according to the diameter of the true lumen as well as to institutional standards.

The delivery system of the device has a so-called self-alignment mechanism, meaning that the precurved inner catheter conforms to the curve of the aortic arch. The window for the supra-aortic branches is mounted so that it automatically aligns to the outer curvature. There are radiopaque markers indicating the beginning, the end and the orientation of the window.

The delivery system of the main body of the device has a 25/26 Fr profile (24/25 Fr on the lower profile RelayPro platform) requiring a minimum access vessel diameter of 8–9 mm; the supra-aortic extensions have a 14 Fr profile. Supplementary Material, Fig. S1 shows a computer-aided design drawing for both the main body and the branches.

## Surgical technique

A bilateral common carotid artery cut-down is used as a standard approach. In the case of a simultaneous LCCA-to-left subclavian artery (LSA) bypass, this procedure is done first, usually with an 8-mm Dacron graft. Afterwards, the main body of the prosthesis is inserted in a retrograde fashion, according to the given diameter of the common femoral arteries or the iliac axis, either via the groin or via the common iliac artery. The tip of the stiff guidewire passes the aortic valve and is located at the tip of the left ventricle. The main body is deployed with the window for the supra-aortic branches towards the outer curvature. Afterwards, the introduction system is removed. As a next step, the right common carotid artery is punctured, the posterior tunnel is cannulated and the first extension to the BCT is inserted. Afterwards, the LCCA is punctured, the anterior tunnel is cannulated and the second extension to the LCCA is inserted.

## Statistical methods

IBM SPSS Statistics 24 for Macintosh (IBM SPSS Inc., Armonk, NY, USA) was used for the statistical analyses. All values are expressed as number (percentage) or mean ± standard deviation. Normal distribution was verified graphically using QQ plots. The 'Student's *t*-test' was used to compare continuous variables. The Spearman correlation was used for preoperative neurological dysfunction and postoperative stroke. We have done an inverse-probability-of-censoring to estimate the risk of death during the follow-up period.

# RESULTS

## Baseline characteristics

Baseline characteristics are shown in Table 2. The majority of patients were men ($n = 33$, 77%), and the median EuroSCORE II was 3.3 ± 1.5. Sixteen patients (37%) had coronary artery disease and 10 patients (23%) had atrial fibrillation. Fourteen patients (33%) had renal impairment of various extents and 18 patients (42%) had extracardiac arteriopathy. Eight patients (19%) had a history of stroke. There was no statistically significant correlation between preoperative neurological disfunction and postoperative stroke (correlation coefficient 0.150; $P = 0.174$).

**Table 2:** Baseline characteristics

| Patients | *n* = 43 |
|---|---|
| Male, *n* (%) | 33 (77) |
| Age (years), mean ± SD | 73 ± 9 |
| EuroSCORE II, mean ± SD | 3.3 ± 1.5 |
| NYHA, *n* (%) | |
| I | 25 (58) |
| II | 8 (19) |
| III | 5 (12) |
| Unknown | 5 (12) |
| CCS, *n* (%) | |
| 0 | 1 (2) |
| 1 | 31 (72) |
| 2 | 5 (12) |
| 3 | 1 (2) |
| Unknown | 5 (12) |
| LVEF (%), mean ± SD | 56 ± 9 |
| Coronary artery disease, *n* (%) | 16 (37) |
| Previous coronary artery bypass grafting, *n* (%) | 0 (0) |
| Recent myocardial infarction, *n* (%) | 0 (0) |
| Valvular heart disease, *n* (%) | 2 (5) |
| Tricuspid aortic valve, *n* (%) | 34 (79) |
| Atrial fibrillation, *n* (%) | 10 (23) |
| PAH, *n* (%) | 2 (5) |
| Renal impairment, *n* (%) | 14 (33) |
| Extracardiac arteriopathy, *n* (%) | 18 (42) |
| Poor mobility, *n* (%) | 9 (21) |
| COPD, *n* (%) | 11 (26) |
| IDDM, *n* (%) | 2 (5) |
| Previous stroke, *n* (%) | 8 (19) |

CCS: left common carotid artery; COPD: chronic obstructive pulmonary disease; IDDM: insulin-dependent diabetes mellitus; LVEF: left ventricular ejection fraction; NYHA: New York Heart Association; PAH: pulmonary arterial hypertension; SD: standard deviation.

## Aortic characteristics

Aortic characteristics are shown in Table 3. Twenty patients (47%) had previous aortic operations or interventions where open infrarenal repair was the most frequent previous aortic operation ($n = 7$, 16%). The underlying thoracic aortic pathology decisive for indicating treatment was aneurysm formation ($n = 31$, 72%) whereas the aetiology was degenerative in 26 patients (61%), RAD in 7 patients (16%) and based on a penetrating atherosclerotic ulceration (PAU) in 8 patients (19%). Four patients (9%) had a bicarotid trunk. The diameters and lengths of both the lesions and the landing zones are shown in Table 3.

## Procedural details

Procedural details are shown in Table 4. Rapid pacing was the most frequently used means of lowering the blood pressure ($n = 34$, 79%). Sixteen patients (37%) had cerebrospinal fluid drainage for prevention of symptomatic spinal cord injury before the procedure. In 34 patients (79%), an LCCA-LSA bypass was performed to maintain LSA perfusion. In 37 patients (86%), an open access to both common carotid arteries was chosen for implanting the bridging stent grafts into the BCT as well as into the LCCA. In 18 patients (42%), the LCCA was clamped during deployment of the main body of the stent graft system to avoid embolization. The mean procedural time was 289 ± 142 min (282 ± 151 min in patients without RAD vs 318 ± 109 min in

**Table 3:** Aortic characteristics

| Patients | N = 43 |
|---|---|
| Underlying aortic disease | |
| Aneurysm, n (%) | 31 (72) |
| Other | 12 (28) |
| Presumed aetiology, n (%) | |
| Degenerative | 26 (61) |
| Post-dissection | 7 (16) |
| PAU | 8 (19) |
| Unknown | 2 (5) |
| Beginning of lesion, n (%) | |
| 0 | 4 (9) |
| 1 | 7 (16) |
| 2 | 24 (56) |
| 3 | 8 (19) |
| End of lesion, n (%) | |
| 2 | 2 (5) |
| 3 | 15 (35) |
| 4 | 26 (61) |
| Morphology, n (%) | |
| Regular arch morphology | 39 (91) |
| Bicarotid trunk | 4 (9) |
| Isolated vertebral artery offspring | 1 (2) |
| Measurements, mean ± SD | |
| Maximum aortic arch diameter (mm) | 62 ± 15 |
| Length, ascending (mm) | 78 ± 15 |
| Diameter, ascending (mm) | 37 ± 3 |
| Length, BCT (mm) | 34 ± 8 |
| Landing zone, BCT (mm) | 26 ± 11 |
| Diameter, BCT (mm) | 15 ± 2 |
| Length, LCCA (mm) | 56 ± 33 |
| Diameter LCCA (mm) | 8 ± 1 |

BCT: brachiocephalic trunk; LCCA: left common carotid artery; PAU: penetrating atherosclerotic ulceration; SD: standard deviation.

**Table 4:** Procedural details

| Patients | N = 43 |
|---|---|
| Intended oversizing (%), mean ± SD | 17 ± 6 |
| Blood pressure lowering, n (%) | |
| Rapid-pacing | 34 (79) |
| Adenosine | 3 (7) |
| IVC occlusion | 5 (12) |
| Unknown | 1 (2) |
| CSF drainage, n (%) | 16 (37) |
| Heparin (IU), mean ± SD | 9674 ± 5896 |
| LCCA-LSA bypass, n (%) | 34 (79) |
| During TEVAR | 22 (51) |
| Before TEVAR | 12 (28) |
| No | 9 (21) |
| LCCA access, n (%) | |
| Open | 37 (86) |
| Seldinger | 4 (9) |
| Unknown | 2 (5) |
| Access for BCT extension, n (%) | |
| Brachial artery | 2 (5) |
| Right subclavian artery | 3 (7) |
| Right common carotid artery | 37 (86) |
| Unknown | 1 (2) |
| Common carotid artery clamping during deployment, n (%) | 18 (42) |
| Operating time (min), mean ± SD | 289 ± 142 |
| Fluoroscopy time (min), mean ± SD | 49 ± 29 |
| Packed red blood cells, mean ± SD | 1.2 ± 2.8 |
| Distal extension (TEVAR) | 9 (21) |

BCT: brachiocephalic trunk; CSF: cerebral spinal fluid; IVC: inferior vena cava; LCCA: left common carotid artery; LSA: left subclavian artery; SD: standard deviation; TEVAR: thoracic endovascular aortic repair.

**Table 5:** Outcomes of all patients

| Patients | N = 43 |
|---|---|
| Deaths, n (%) | 4 (9) |
| Stroke, n (%) | 11 (26) |
| Disabling | 3 (7) |
| Non-disabling | 8 (19) |
| Transient SCI, n (%) | 1 (2) |
| Renal failure, n (%) | 2 (5) |
| Pneumonia, n (%) | 4 (9) |
| Neck haematoma/bleeding, n (%) | 3 (7) |
| ICU stay (days), mean ± SD | 3 ± 3 |
| Hospital stay (days), mean ± SD | 14 ± 11 |
| Endoleak, n (%) | 7 (16) |
| Ia | 1 (2) |
| Ib | 1 (2) |

ICU: intensive care unit; SCI: spinal cord injury; SD: standard deviation.

patients with RAD; $P = 0.59$); the mean fluoroscopy time was 49 ± 29 min. Distal thoracic endovascular aortic repair extension was done in 9 (21%) patients during branched endovascular aortic arch repair. Supplementary Material, Fig. S2 shows a computed tomography angiogram of a patient before and 2 years after relay branch implantation.

## Outcome

Clinical outcome is shown in Table 5. Four patients (9%) died in-hospital. Of these, 2 patients had a disabling stroke and 2 died of pneumonia-related septic shock. Another patient who survived also had a disabling stroke (7%). Eight patients (19%) had a non-disabling stroke. Details of neurological injury are shown in Table 6. The mean hospital stay was 14 ± 11 days. Type IA and type IB endoleaks were observed in 1 patient each (4%). Retrograde perfusion of the lesion via the LSA was seen in 3 patients (7%).

## Outcome in patients with residual aortic dissection

Clinical outcome in patients with RAD is shown in Table 7. There were no in-hospital deaths, and no disabling strokes were observed. One patient (13%) experienced a non-disabling stroke. Mean hospital stay was 19 ± 17 days. One post-procedural type IA endoleak was observed and managed conservatively. One patient who refused open surgery died after an acute retrograde type A aortic dissection 43 days after treatment.

## Follow-up data

The mean follow-up was 16 ± 18 months. Eleven patients (23%) died during the follow-up period. Supplementary Material, Fig. S3 shows an inverse probability of censoring to estimate the risk of death during follow-up. The most commonly observed reason

**Table 6:** Details of perioperative neurological injury

| Stroke patients | Previous stroke | Disabling | mRS | Description |
|---|---|---|---|---|
| 1 | No | No | 3 | Bilateral |
| 2 | Yes | No | | Left hemisphere and cerebellar |
| 3 | No | Yes | 6 | Haemorrhage |
| 4 | Yes | No | 1 | Right hemisphere |
| 5 | No | Yes | 6 | Left hemisphere |
| 6 | No | No | 1 | Left hemisphere |
| 7 | YEs | No | 1 | |
| 8 | Yes | No | 1 | Bilateral |
| 9 | No | No | 1 | |
| 10 | No | No | 2 | |
| 11 | No | Yes | 5 | |

mRS: modified Rankin scale.

**Table 7:** Outcome of patients with residual aortic dissection

| Patients | *n* = 8 |
|---|---|
| Deaths, *n* (%) | 0 (0) |
| Stroke, *n* (%) | 1 (13) |
| Disabling | 0 (0) |
| Non-disabling | 1 (13) |
| Transient SCI, *n* (%) | 0 (0) |
| Renal failure, *n* (%) | 0 (0) |
| Pneumonia, *n* (%) | 1 (13) |
| Neck haematoma/bleeding, *n* (%) | 0 (0) |
| ICU stay (days), mean ± SD | 3 ± 3 |
| Hospital stay (days), mean ± SD | 19 ± 17 |
| Follow-up time (months), mean ± SD | 15 ± 15 |
| Follow-up deaths, *n* (%) | 1 (13) |
| Type A dissection | 1 (13) |

ICU: intensive care unit; SCI: spinal cord injury; SD: standard deviation.

of death during follow-up was sepsis/pneumonia (*n* = 3, 8%). New type IA and type IB endoleaks were observed in 1 patient each (4%). Retrograde perfusion of the lesion via the LSA was seen in 3 patients. One type IA endoleak was observed and another was treated via embolization in combination with fixation of the proximal main body stent graft component via the Aptus system (Medtronic, Santa Rosa, CA, USA). Two endoleaks via retrograde LSA perfusion were treated by coil embolization; another type IC endoleak at the level of the BCT was treated via a leg extension (Ovation iX, Endologix, Santa Rosa, CA, USA). During follow-up, shrinkage of the aneurysmal sac of 2 ± 8 mm could be observed.

## DISCUSSION

The results of endovascular aortic arch repair using the Relay Branch system in a selected patient population with regard to technical success were good. In-hospital mortality was acceptable, the number of disabling strokes was low and the technical success was high. A non-disabling stroke is a major concern, and every effort has to be made to reduce this to a minimum. The best outcomes were seen in patients with the underlying pathology of RAD. Finally, more data are needed.

The baseline characteristics of this patient cohort are comparable to those of previously published series, in particular with regard to the presence of cardiac and extracardiac risk factors [4–8]. It should be clearly stated that these patients currently present a highly selected patient population. For example, in the first author's institution, 1 out of 10 patients undergo the Relay Branch implant whereas the remaining 9 patients undergo classical aortic arch replacement using the frozen elephant trunk technique.

Nearly half of this patient cohort had previous aortic interventions, the most frequent being open infrarenal repair. This fact underlines the need to regard the aorta as an organ that needs monitoring in all segments, which justifies the increasing demand for aortic centres and their outpatient clinics [1]. Aneurysmal formation was the most commonly observed thoracic aortic pathology. However, several underlying conditions with very different underlying disease mechanisms may lead to this common final path. Degenerative aneurysmal formation was the most common underlying pathology followed by aneurysmal formation on the basis of PAU and finally by aneurysm formation on the basis of RAD. The main difference here is that PAU is an obliterative aortic disease that makes these patients prone to multisite arterial disease such as coronary artery disease, carotid artery disease or peripheral arterial disease. Consequently, procedural risk, in particular for access vessel challenges, and most importantly for stroke, is higher [10]. It remains of utmost importance to anticipate risk during screening and to link findings of preoperative imaging to the potential complications caused by wire manipulation early and to rethink the treatment strategy. Open surgery might be the better option here because manipulations can be minimized.

One-third of patients had cerebrospinal fluid drainage prior to the procedure. The prevention of symptomatic spinal cord injury remains a major component during thoracic aortic procedures, and the use of cerebrospinal fluid drainage is a major contributor to reducing the occurrence to a minimum by permitting swelling of the spinal cord during an ischaemic insult [11]. Another major contributor is the preservation of inflow to the LSA, which was achieved by LCCA-LSA bypass in 79% of patients. According to the collateral network concept and to the 4-territory concept, the preservation of LSA inflow attenuates ischaemic injury potentially caused by occlusion of the segmental arteries [12–14]. Some prefer to explain the importance of the LSA as being related to the contribution of the left vertebral artery to the posterior cerebellar circulation as well as to the feeding of the anterior spinal artery by LSA offspring balloon occlusion and contralateral angiography. However, the notion within the community has shifted towards a liberal strategy of prophylactic LSA revascularization to prevent neurological injury at any level.

In the majority of patients, a surgical cut-down to both common carotid arteries was used to implant the bridging stent grafts into the BCT and the LCCA. Percutaneous access was used restrictively, which is reasonable because the texture of the common carotid arteries may be second best for percutaneous closure systems and there is limited experience concerning how the intravascular component of these closure systems will behave in the mid- and long term. In 42%, the respective common carotid artery was clamped during deployment of the bridging stent grafts, which is one of the useful adjuncts preventing embolization during deployment. Debris is 1 component, and air embolism is another. Despite accurate flushing and de-airing of stent graft delivery systems, remaining air remains an issue but may be device- and delivery system-specific [15, 16].

In-hospital mortality was 9%. Of these, 2 patients had a disabling stroke and died of the sequelae. The others died of pneumonia-related septic shock. In this series, we had a high rate of non-disabling strokes of 19%. Stroke, irrespective of extent, is one of the most devastating events after any kind of cardiovascular procedure and puts the entire effort of treatment into perspective. The reasons are manifold, but the underlying pathology (PAU at highest risk), anatomy-related risk factors requiring substantial wire manipulation and any atherosclerotic effect of the supra-aortic branches are the most decisive [1]. The benchmark here is without doubt the rate of both disabling and non-disabling strokes in patients undergoing classical aortic arch replacement using the frozen elephant trunk technique, which is either equal to or even lower than those in most recent series with regard to disabling stroke and definitely lower with regard to non-disabling stroke [2, 17]. Also here, the underlying pathology makes the most difference. Intra- and postoperative anticoagulation and antiaggregation schemes also have to be considered as contributors, and a protocol acceptable to all still remains to be defined.

This series had a low rate of type I endoleaks. Because the entire zone 0 serves as a potential landing zone and because the length of the landing zone is a direct surrogate of the presence or absence of type I endoleaks, this connotation becomes evident.

According to others, we paid specific attention to the subgroup of patients with RAD because recent work indicates a favourable outcome [18]. We were able to confirm these findings with no deaths and no disabling strokes in this subgroup; 1 patient experienced a non-disabling stroke with complete resolution of symptoms. Also, it is important to understand the underlying disease process because the intimal surface of these patients is usually smooth. Any deleterious effects of atherosclerosis are the exception, not the rule.

The median follow-up period is still short. Mortality during the follow-up period was high. The deaths were mainly non-aortic-related. However, they reflect the disease load of these patients and should be interpreted as a plea for strict selection criteria in order to choose the patients who are likely to die of aortic disease and not the patients who will die with aortic disease [7]. Late endoleak formation was rare but it did occur. Late type IA endoleak formation in particular may mirror the chronic compliance mismatch between the highly elastic native ascending aortic wall and the still very rigid stent graft, which has also been reported to be a trigger for a decrease in left ventricular function over time [19].

Finally, the decision as to the suitability or non-suitability for either open surgery or this approach may be subjective, and 2 surgeons might make different decisions about the same patient based on their personal experience. In addition, we still lack an adequate preoperative risk stratification tool in aortic medicine that is analogous to the EuroSCORE or the Society of Thoracic Surgeons score. It is likely that, like transcatheter aortic valve replacement, this approach, as it is in this series, is offered primarily to patients with a high disease load, which might also mirror the mortality and stroke rate observed. Currently, and this is the unanimous opinion of the authors, the most important details remain the anatomical suitability and an understanding the underlying disease process because the procedure is straightforward when the anatomical characteristics are adequate. In contrast, it can be highly challenging, in particular with regard to the extent of wire manipulation and associated collateral injury in patients with complex anatomies and in those with a high atherosclerotic load.

## Limitations and strengths

This series has a large number of contributing centres but with a low patient number from each. However, because the technology is still new and has not yet spread, this study remains the only meaningful effort to acquire data from early adopters. Having stated that, this series is the largest of its kind reporting results with this stent graft system. Because successes, challenges and limitations have been equally distributed among the contributing centres, this series provides a realistic outlook and is able to determine the needs to be met and the hurdles to be faced in the future. A statistically meaningful comparison between the different groups of patients (RAD versus other aetiologies) was not possible because of the still low patient numbers. Also, although we did attempt to improve the reporting of cerebrovascular complications, this information was obtained retrospectively and with the heterogeneous involvement of a neurologist [20].

## CONCLUSION

The results of endovascular aortic arch repair using the Relay Branch system in a selected patient population with regard to technical success are good. In-hospital deaths are acceptable, the number of disabling strokes is low and the technical success is high. Non-disabling stroke is a major concern, and every effort has to be made to reduce this to a minimum. The best outcome is seen in patients with the underlying pathology of RAD. Finally, more data are needed.

## SUPPLEMENTARY MATERIAL

Supplementary material is available at *EJCTS* online.

**Conflict of interest:** Martin Czerny is a consultant to Terumo Aortic and Medtronic. He received speaking honoraria from Bentley and Cryolife and is a shareholder of TEVAR Ltd. Bartosz Rylski and Robin Heijmen are consultants to and Joost van Herwaarden is a proctor for Terumo Aortic.

## Author contributions

**Martin Czerny:** Conceptualization; Data curation; Investigation; Methodology; Writing—original draft; Writing—review & editing. **Tim Berger:** Conceptualization; Software; Validation; Writing—original draft. **Stoyan Kondov:** Conceptualization; Data curation; Investigation; Methodology. **Matthias Siepe:** Conceptualization; Supervision; Validation; Writing—original draft. **Bertrand Saint Lebes:** Data curation; Formal analysis; Supervision; Validation. **Fatima Mokrane:** Data curation; Formal analysis; Supervision; Validation. **Herve Rousseau:** Conceptualization; Data curation; Validation; Visualization. **Mario Lescan:** Conceptualization; Supervision; Validation; Writing—original draft. **Christian Schlensak:** Conceptualization; Methodology; Validation; Writing—original draft. **Mateja Andic:** Investigation; Methodology; Visualization; Writing—original draft. **Constatijn Hazenberg:** Conceptualization; Methodology; Validation; Writing—original draft. **Trijntje Bloemert-Tuin:** Conceptualization; Formal analysis; Methodology; Validation. **Sue Braithwaite:** Conceptualization; Methodology; Visualization; Writing—original draft. **Joost van Herwaarden:** Conceptualization; Methodology; Supervision; Validation. **Alexander Hyhlik-Dürr:** Conceptualization; Validation; Writing—original draft. **Yvonne Gosslau:** Conceptualization; Methodology; Visualization; Writing—original draft. **Luís Mendes Pedro:** Conceptualization; Methodology; Validation; Writing—original draft. **Pedro Amorim:** Conceptualization; Methodology; Validation; Writing—original draft. **Toru Kuratani:** Conceptualization; Data curation; Methodology; Writing—original draft. **Stephen Cheng:** Conceptualization; Methodology; Validation; Writing—original draft. **Robin Heijmen:** Conceptualization; Methodology; Validation; Writing—original draft. **Emma van der Weijde:** Conceptualization; Methodology; Validation; Writing—original draft. **Eliza Pleban:** Conceptualization; Methodology; Validation; Writing—original draft. **Piotr Szopiński:** Conceptualization; Methodology; Validation; Writing—original draft. **Bartosz Rylski:** Conceptualization; Data curation; Methodology; Writing—original draft; Writing—review & editing.

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