Aorta and Major Branches

Eur J Vasc Endovasc Surg (2024) 68, 456—466

EJVES Open Access

# Editor's Choice – Sex Related Anatomical Differences in Patients With Aortic Arch Pathology and Their Impact on the Feasibility of Double and Triple Branched Endografts

**Daniel Becker** [a,b], **Nikolaos Tsilimparis** [a,b], **Ahmed Ali** [a,b], **Jan Stana** [a,b], **Zsuzsanna Mihály** [a,b], **Maximilian Pichlmaier** [a,c], **Sven Peterss** [a,c], **Carlota F. Prendes** [a,b,*]

[a] University Aortic Centre Munich, LMU University Hospital, Munich, Germany
[b] Department of Vascular Surgery, LMU University Hospital, Munich, Germany
[c] Department of Cardiac Surgery, LMU University Hospital, Munich, Germany

## WHAT THIS PAPER ADDS

Evidence exists regarding sex related feasibility differences across off the shelf endovascular devices for the treatment of thoraco-abdominal and complex abdominal aortic pathologies. However, there is a lack of data on sex related differences regarding aortic arch anatomy and their impact on arch branch endograft feasibility. In this patient cohort, the proximal landing zone length was significantly shorter in female patients, who presented a decreased feasibility for double arch branched devices compared with male patients (35.3% *vs.* 58.4%; $p = .015$) and, to a lesser extent, for triple arch branch devices (31.4% *vs.* 47.5%, $p = .081$).

**Objective:** To evaluate sex based differences in ascending aorta and arch anatomy in patients with underlying proximal aortic disease and to evaluate their impact on feasibility for total endovascular repair with custom made, branched arch devices.

**Methods:** This was a retrospective cross sectional review of all patients undergoing open and or total endovascular arch repair due to distal ascending aorta and or aortic arch pathologies in a single high volume aortic centre between 2012 and 2022. Anatomical ascending aorta and aortic arch parameters were analysed on a flow centreline on a dedicated 3D workstation. Sex related differences of the ascending aorta, aortic arch, and supra-aortic vessels were evaluated. Subsequently, four endovascular devices were assessed for feasibility: double and triple branched devices both for the Zenith (Cook Medical) and Relay (Terumo Aortic) platforms, first in accordance with the instructions for use and then considering the possibility of adjunctive cervical debranching. The primary endpoints were sex specific differences in aortic anatomy, while secondary endpoints included sex based feasibility of branched endograft devices.

**Results:** During the study period, 395 patients underwent total aortic arch repair, of whom 152 (51 female, 33.5%) had high quality computed tomography angiograms available and were included in the study. Female patients had a shorter proximal landing zone than males (22 mm *vs.* 47 mm; $p < .001$). Left subclavian artery dissection was more frequent in men (24.8% *vs.* 3.9%; $p < .001$). Other anatomical parameters showed a similar distribution between sexes. Female patients presented a lower feasibility for double branched devices (35.3% *vs.* 58.4%; $p = .015$) as well as a tendency for lower feasibility rates for triple branched devices (31.4% *vs.* 47.5%; $p = .081$).

**Conclusion:** Although most ascending aortic and arch parameters showed similar trends in both sexes, the availability of a suitable proximal landing zone was lower in female patients. Consequently, female patients had lower feasibility rates for double arch branched endografts and, to lesser extent, for triple arch branched endografts.

**Keywords:** Anatomy, Aortic arch, Branched endograft, Custom made, Feasibility, Sex

Article history: Received 18 November 2023, Accepted 7 June 2024, Available online 13 June 2024

---

* Corresponding author. Department of Vascular Surgery, LMU University Hospital, Munich, Germany.
*E-mail address:* Carlota.f.prendes@gmail.com (Carlota F. Prendes).
@CarlotaFPrendes

https://doi.org/10.1016/j.ejvs.2024.06.012

## INTRODUCTION

Aortic arch pathologies are often associated with other thoracic and or thoraco-abdominal aortic pathologies, making surgical and endovascular treatment challenging.[1] While open surgical repair remains the gold standard, up to 20% of patients are considered unfit, either due to comorbidities, age, or prior cardiac surgery.[2] Alternative solutions for these unfit patients include hybrid repair, combining supra-aortic debranching for extension of the proximal landing zone followed by thoracic endovascular aortic repair, or total endovascular repair with chimney, branched, fenestrated, and *in situ* fenestrated stent graft techniques.[3,4] Total endovascular solutions have demonstrated promising short term outcomes, with technical success and 30 day mortality rates of 96.7% and 3.3 – 4.9%, respectively.[5,6] Additionally, 30 day stroke and spinal cord ischaemia rates have been reported to be 5.1 – 10.6% and 1.4%, respectively.[7–9]

Although the understanding of sex based differences in aortic pathologies is still in its infancy, women appear to have worse outcomes than men following medical and surgical treatment, with higher 30 day aortic related mortality (11% *vs.* 7.4%), stroke (8.8% *vs.* 5.5%), and major adverse event rates (31% *vs.* 27%), respectively, alongside a disproportionately high incidence of aortic dissection.[10,11] Despite this, female patients have been frequently underrepresented in cardiovascular and aortic research.[12] Several studies have been performed to evaluate the influence of age, body surface area (BSA), sex, and type of aortic pathology on ascending aortic and aortic arch morphology, finding women to have smaller aortic diameters and a shorter ascending aortic length ($p < .010$), even after adjustment for BSA.[13,14] However, these studies were performed in healthy individuals without underlying aortic disease, so their findings cannot easily be extrapolated to patients with aortic arch disease and its impact on feasibility for endovascular solutions. Grandi *et al.* evaluated the impact of sex related anatomical differences on the feasibility of repair of thoraco-abdominal aneurysms, reporting that 22% of women could undergo treatment with off the shelf solutions compared with 45% of men.[15] However, there are limited data regarding sex based anatomical and feasibility differences specific to the aortic arch.

This study aimed to analyse sex based differences in aortic arch anatomy among patients with ascending aortic and aortic arch disease, and their impact on the feasibility of total endovascular aortic arch repair using custom made double or triple branched endografts.

## MATERIALS AND METHODS

A single centre, retrospective, cross sectional study was conducted between January 2012 and December 2022 on consecutive patients undergoing surgery for pathologies affecting the ascending aorta and or aortic arch, including open, hybrid, and endovascular repair. The study followed the reporting guidelines from the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) statement for cohort studies[16] and was approved by the Ethical Committee of Ludwig Maximilian University (Munich, Germany) (protocol no. 561-15).

Inclusion criteria were broad and included patients with: (1) aneurysmal pathology, degenerative or post-dissection, involving the distal ascending aorta and or aortic arch; (2) penetrating aortic ulcers, pseudoaneurysms, traumatic injuries of the distal ascending aorta and or aortic arch, and intramural haematomas; (3) a prior ascending aortic or hemiarch graft replacement; and (4) prior biological or mechanical valve implantation.

Only patients with either an acute type A aortic dissection and or an ascending aortic aneurysm with an aortic root aneurysm were excluded.

Patients without a pre-operative computed tomography angiogram (CTA) of the complete aorta and those with a slice thickness $>$ 1.25 mm were also excluded from this analysis given that a detailed assessment of the anatomy and endovascular feasibility was not possible.

### *Study endpoints*

The primary endpoint was sex specific differences in aortic arch and supra-aortic vessel anatomy. The secondary endpoint was the sex based anatomical feasibility of currently available custom made branched aortic arch endograft devices, firstly according to strict instructions for use (IFU) criteria, and secondly according to an extended IFU with the use of adjunctive procedures (extended clinical feasibility), mainly cervical debranching.

### *Anatomical analysis*

Analysis of images was performed on a dedicated 3D workstation (Aquarius Intuition viewer; TeraRecon, Durham, NC, USA) with the generation of a semi-automatic and manually adjusted aortic flow centreline (CLF). The CLF was then automatically expanded, creating a CLF of the outer and inner curvature, so that a total of three aortic CLFs (outer curvature, midaortic, and inner curvature) were generated for each patient (Fig. 1A – E). Additional centrelines were made from the sinotubular junction (STJ) to the supra-aortic vessels.

Aortic diameters were measured orthogonally to the midaortic CLF and recorded at the level of the STJ, the proximal landing zone (PLZ), the supra-aortic vessels, and the distal landing zone. In patients with post-dissection aneurysms, diameter measurements were performed in the true lumen according to the croissant–doughnut technique (Fig. 1F, G). In a dissected aorta with a partially collapsed true lumen with a dumbbell shape, the diameter was measured based on the maximum length of the dumbbell (Fig. 1F, G).[17]

A suitable PLZ was defined as a healthy parallel segment of the ascending aorta, free of thrombus and calcification (the presence or absence of thrombus and or calcification was assessed visually by observers), with a length of $\geq$ 30 mm and a diameter between 28 – 43 mm (IFU for branched Relay endograft) or a length of $\geq$ 40 mm and a diameter of

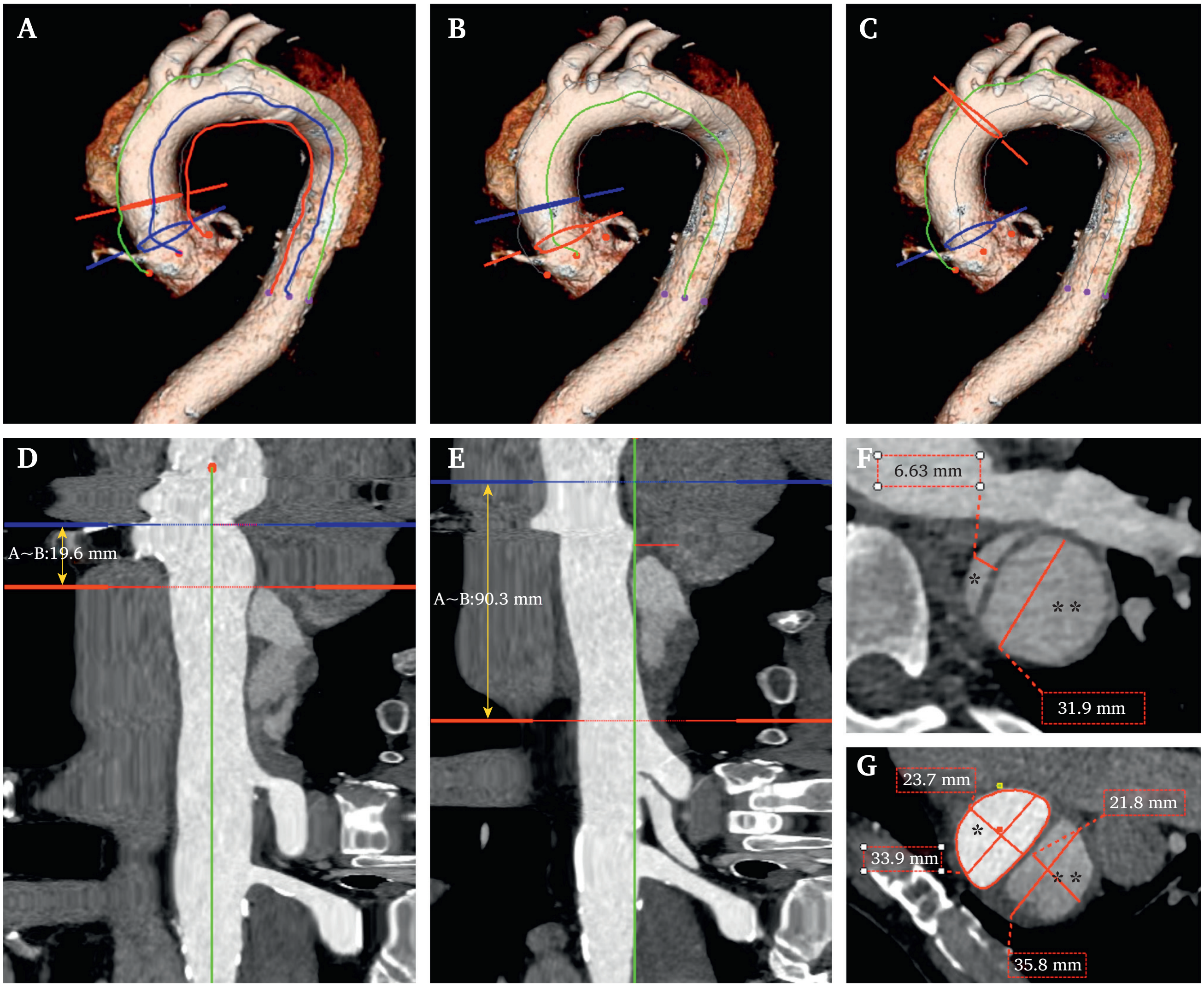


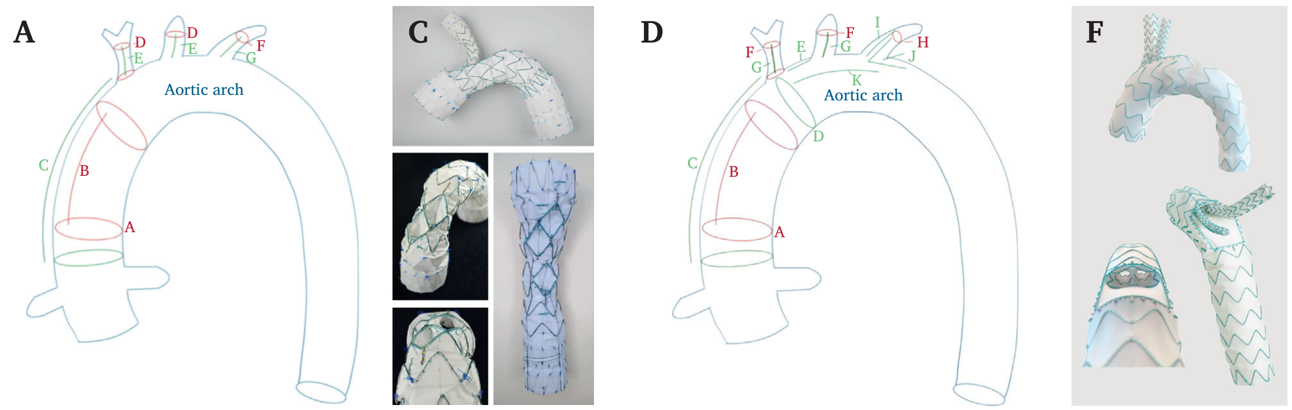
**Figure 1.** (A) 3D computed tomography angiography (CTA) with three aortic centreline flows (CLFs): outer curvature (green line); mid aortic (blue line); and inner curvature (red line). (B) Proximal landing zone: distance between sinotubular junction (red line) and beginning of pathology in midaortic CLF (blue line). (C) Outer curvature CLF (green line): distance between sinotubular junction (blue line) and innominate artery (red line). (D) Length of proximal landing zone in centreline (distance between blue and red line). (E) Length of ascending aorta between sinotubular junction and brachiocephalic trunk (distance between blue and red line). (F) Croissant shape true lumen (*) and false lumen (**). The formula used to calculate the diameter was $(length + width)/2$. (G) True lumen (*) and false lumen (**). The formula used to calculate the diameter was $(length + width)/2$.

24 − 38 mm (IFU for branched Cook endograft), located distal to the take off of the coronary arteries and proximal to the take off of the first supra-aortic trunk. The distal landing zone was defined as a healthy parallel segment of thoracic aortic, free of thrombus and calcification, with a length of $\geq$ 20 mm located distal to the left subclavian artery (LSA).

Lengths measured on the outer curvature CLF included distances: (1) from the STJ to the origin of the brachiocephalic trunk (BCT); (2) between the STJ and the left common carotid artery (LCCA); (3) between the STJ and LSA; (4) from the proximal edge of the BCT to the proximal edge of the LCCA; (5) from the proximal edge of the LCCA to the proximal LSA; and (6) from the proximal edge of the LCCA to the distal LSA (Fig. 1).

The sealing lengths of the BCT and LSA were measured using the midaortic CLF, from their origin to the take off of the right subclavian artery and the left vertebral artery, respectively. Diameters were measured orthogonally to their respective CLF. The clock positions of the supra-aortic vessels were measured orthogonally to the respective CLF, as described in a previous publication.[18] Anatomical variations (arteria lusoria, bovine arch, etc.) as well as dissection of the supra-aortic trunks were also documented.

Arch tortuosity was calculated based on a modification of the method proposed by Alhafez *et al.*,[19] in which a horizontal line is drawn from the midpoint of the ascending aorta at the STJ to the midpoint of the descending thoracic aorta at the level of the right pulmonary artery. The distance of the arch between these two points was then measured



**B**

| IFU feasibility criteria for the Zenith double and triple branch devices | | |
|---|---|---|
| IFU criteria triple arch branch | IFU criteria double arch branch | A - Diameter PLZ: 24–38 mm |
| | | B - Length PLZ: ≥ 40 mm |
| | | C - STJ-BCT outer curvature: 50 mm |
| | | D - Target vessel diameter BCT/LCCA: ≤ 20 mm |
| | | E - Target vessel length BCT/LCCA: ≤ 20 mm |
| | | F - Diameter LSA: ≤ 20 mm |
| | | G - Length LSA: ≥ 20 mm |

**E**

| IFU feasibility criteria for the Relay double and triple branch devices | | |
|---|---|---|
| IFU criteria triple arch branch | IFU criteria double arch branch | A - Diameter PLZ: 28–43 mm |
| | | B - Length PLZ: > 30 mm |
| | | C - STJ-BCT outer curvature: ≥ 70 mm |
| | | D - Aortic diameter at BCT level: ≥ 20 mm |
| | | E - Distance BCT – LCCA: ≤ 45 mm |
| | | F - Diameter target vessel BCT/LCCA: ≤ 22 mm |
| | | G - Target vessel length: BCT/LCCA: ≥ 25 mm |
| | | H - Diameter LSA: ≤ 22 mm |
| | | I - Length LSA: ≥ 25 mm |
| | | J - LSA angulation ≥ 75° |
| | | K - Distance between proximal BCT to distal LSA: ≤ 65 mm |

**Figure 2.** (A − C) Endograft and feasibility criteria for the Zenith double and triple arch devices, including (A) schematic representation of the endograft and anatomical limitations, including a (B) list of all the instructions for use (IFU) criteria, as well as (C) images of the actual device. (D − F) Endograft and feasibility criteria for the Relay double and triple arch devices, including (D) schematic representation of the endograft and anatomical limitations, including a (E) list of all the IFU criteria, as well as (F) images of the actual device. BCT = brachiocephalic trunk; LCCA = left common carotid artery; LSA = left subclavian artery; STJ = sinotubular junction; PLZ = proximal landing zone.

on the mid aortic CLF, and the tortuosity index was obtained by calculating the ratio of the distance measured on the CLF to the length of the horizontal line. The type of aortic arch was defined based on the relationship between the vertical distance from the origin of the BCT to the top of the arch, and the diameter of the LCCA, with a ratio $< 1$ corresponding to type 1, a ratio of $1 - 2$ corresponding to type 2, and a ratio of $> 2$ corresponding to type 3.[19]

To ensure consistency and reproducibility in the measurements, the first investigator (D.B.) performed and saved the measurements on the TeraRecon workstation. A second investigator (C.F.P.) went through all measurements again and adjusted them when in disagreement or accepted them when in accordance. For any queries, a senior investigator (N.T.) was involved. Finally, one set of measurements, validated by either two or three investigators, was created.

### *Device description and feasibility criteria*

The feasibility of four different custom made devices was assessed: the double and triple Zenith inner branched arch endografts (Cook Medical, Bloomington, IN, USA) and the Relay double and triple arch branched endografts (Terumo Aortic, Sunrise, FL, USA). The Zenith branched arch device presents two antegrade inner branches with diamond shaped openings on the outer curvature for alignment with the BCT and LCCA. In the triple branch configuration, the stent graft includes an additional retrograde inner branch intended for the LSA (Fig. 2A − C). The Relay arch device has a large window on the outer curvature, with two inner tunnels intended for the BCT and LCCA.[20] In the triple branch configuration, the three branches must fit inside a 65 mm long and 26 − 38 mm wide window. The third LSA branch requires a transition angle of > 75° after deployment. The full anatomical criteria (IFU) for all four endografts are presented in Figure 2D − F.

### *Feasibility analysis*

Feasibility was evaluated according to the anatomical IFU. Patients were first evaluated for triple arch repair; if this was not feasible, re-assessment was undertaken for double arch repair and the concomitant use of a left carotid—subclavian bypass. Those who fell outside strict IFU when considered for double or triple branched repair owing to an inadequate BCT landing zone were re-considered for endovascular repair with the adjunct of a right carotid—subclavian bypass. These patients were then considered as having extended feasibility criteria. In addition, those with anatomical variations that were deemed unfeasible for endovascular repair with triple branched devices, such as patients with arteria lusoria, were also considered feasible if solvable via endovascular means plus the use of adjunctive cervical debranching (right carotid—subclavian bypass and plugging of the origin of the arteria lusoria).[20,21] Reports of successful endovascular aortic arch repair in patients with mechanical aortic valve replacement have been published; for the purposes of this study, they were considered to be feasible for endovascular treatment.[22]

### *Subgroup analysis*

Given that the primary analysis included patients with prior ascending aortic replacement, a subanalysis was made including only patients without prior ascending aorta or aortic arch replacement in order to eliminate a potential error or bias in the anatomical and feasibility estimations.

### *Statistical analysis*

Normality of continuous data was tested with the Kolmogorov—Smirnov test. Continuous variables are expressed as the mean ± standard deviation when normally distributed, and as the median and interquartile range (IQR) when not normally distributed. Categorical variables are expressed as numbers and percentages. For the sex based anatomical analysis, the full patient cohort was analysed according to sex, comparing patient demographics, anatomical parameters, and suitability for each of the endografts using Pearson's $\chi^2$ test or Fisher's exact test where applicable. Student's *t* test and analysis of variance (ANOVA) were used for non-parametric data. Variables with a $p$ value of $< .20$ in univariable analysis were included in a multivariable regression model. A $p$ value of $< .050$ was considered statistically significant. All statistical analyses were performed with IBM SPSS Statistics for Windows Version 26.0 (IBM Corp., Armonk, NY, USA).

## RESULTS

### *General cohort*

Of 299 patients who underwent aortic arch repair during the study period, 152 patients had good quality, thin sliced CTAs and were ultimately included in the study (Fig. 3). Of the 232 patients who underwent open arch repair, 90 were included in this analysis, whereas 142 were excluded (78 [54.9%] due to clinical criteria and 64 [45.1%] due to missing or poor quality CTAs) (Supplementary Tables S1 and S2). Of the patients who underwent endovascular repair ($n = 67$), three were excluded due to acute type A dissections and two due to poor CTA quality (7.4%).

The mean age of the cohort was 66.2 ± 13 years and 51 patients (33.5%) were female, with 90 patients (59.2%) undergoing open surgical repair and 62 (40.8%) undergoing endovascular treatment. Female patients were older (69.7 ± 10.3 years *vs.* 64.4 ± 140 years; $p = .009$), had a smaller BSA (1.65 ± 0.34 $m^2$ *vs.* 2.17 ± 0.45 $m^2$; $p < .001$), and a lower body mass index (BMI) (25.9 ± 4.7 $kg/m^2$ *vs.* 26.9 ± 4.7 $kg/m^2$; $p < .001$). Most patients underwent treatment for a post-dissection aneurysm (44.1%) secondary to either a type A, non-A, non-B, or type B acute aortic dissection. Prior ascending aorta and aortic valve replacement was documented in 33.6% and 12.5%, respectively. The median aortic diameter was 58 mm (range, 34 — 110 mm). Full patient demographics are summarised in Table 1.

### *Anatomical analysis*

Most patients (52.6%) presented a type 1 arch configuration, without statistically significant differences between sexes. Anatomical variations were present in 38 patients (25.0%), the most frequent being a bovine arch (14.5%), followed by an aberrant left vertebral artery (5.9%), without

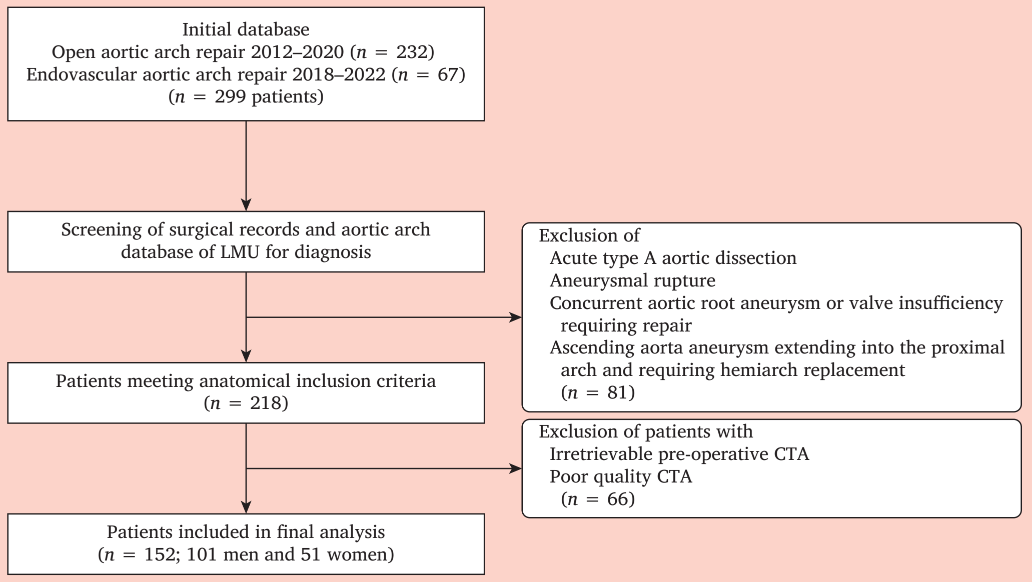


**Figure 3.** Flowchart of patient selection. CTA = computed tomography angiography; LMU = Ludwig Maximilian University.

**Table 1.** Baseline demographic characteristics of the 152 patients with ascending aortic and aortic arch pathology included in this study, for the whole patient cohort and by sex.

| Characteristic | Total ($n = 152$) | Male ($n = 101$) | Female ($n = 51$) | $p$ value |
|---|---|---|---|---|
| Age − y | 66.2 ± 13 | 64.4 ± 14.0 | 69.7 ± 10.3 | .009 |
| BSA − $m^2$ | 2.0 ± 0.5 | 2.2 ± 0.5 | 1.7 ± 0.3 | <.001 |
| BMI − $kg/m^2$ | 26.6 ± 4.7 | 26.9 ± 4.7 | 25.9 ± 4.7 | <.001 |
| *Indication for surgery* | | | | .78 |
| Degenerative aneurysm | 53 (34.9) | 33 (32.7) | 20 (39.2) | .48 |
| Post-dissection aneurysm | 67 (44.1) | 47 (46.5) | 20 (39.2) | .49 |
| Acute dissection | 4 (2.6) | 3 (3.0) | 1 (2.0) | 1.0 |
| Intramural haematoma | 3 (2.0) | 1 (1.0) | 2 (3.9) | .26 |
| Penetrating aortic ulcer | 10 (6.6) | 7 (6.9) | 3 (5.9) | 1.0 |
| Other | 15 (9.9) | 10 (9.9) | 5 (9.8) | 1.0 |
| *Valve, ascending aorta, and aortic arch surgical history* | | | | |
| Aortic arch replacement | 51 (33.6) | 39 (38.6) | 12 (23.5) | .33 |
| TEVAR distal LSA | 9 (5.9) | 6 (5.9) | 3 (5.9) | 1.0 |
| Prior aortic valve replacement | 19 (12.5) | 14 (13.9) | 5 (9.8) | .61 |

Data are presented as mean ± standard deviation or $n$ (%). BSA = body surface area; BMI = body mass index; TEVAR = thoracic endovascular aortic repair; LSA = left subclavian artery.

statistically significant differences between groups. Aortic and supra-aortic vessel diameters were similar between groups. Regarding lengths, female patients had a significantly shorter PLZ (22 [0, 50] mm *vs.* 47 [24, 61] mm; $p < .001$), although all other measured lengths were similar across groups. Finally, the only statistically significant difference in supra-aortic vessel anatomy was a greater rate of a dissected LSA in male patients (25/101 [24.8%] *vs.* 2/51 [3.9%]; $p < .001$) (Table 2). When looking specifically at patients with a native ascending aorta and aortic arch

**Table 2.** Comparison of anatomical parameters of the ascending aorta, aortic arch, and supra-aortic vessels, for the whole patient cohort ($n = 152$) and according to sex.

| Parameter | Total ($n = 152$) | Male ($n = 101$) | Female ($n = 51$) | $p$ value |
|---|---|---|---|---|
| *Type of arch* | | | | .28 |
| Type 1 | 81 (53.3) | 55 (54.5) | 26 (50.9) | |
| Type 2 | 40 (26.3) | 29 (28.7) | 11 (21.6) | |
| Type 3 | 31 (20.4) | 17 (16.8) | 14 (27.4) | |
| *Anatomical variations* | 38 (25.0) | 27 (26.7) | 11 (21.6) | .41 |
| Bovine arch | 22 (14.5) | 15 (14.9) | 7 (13.7) | 1.0 |
| Aberrant right subclavian artery | 7 (4.6) | 5 (4.9) | 2 (3.9) | 1.0 |
| Aberrant left vertebral artery | 9 (5.9) | 7 (6.9) | 2 (3.9) | .72 |
| Arch tortuosity | 1.8 ± 0.43 | 1.8 ± 0.54 | 1.8 ± 0.53 | .70 |
| *Ascending aorta and AA diameters* | | | | |
| Sinotubular junction − mm | 34 (31, 38) | 35 (32, 38) | 33 (30, 35) | .40 |
| Maximum AA diameter − mm | 38 (34, 45) | 37 (34, 43) | 41 (34, 52) | .48 |
| Minimum AA diameter − mm | 32 (29, 35) | 32 (30, 36) | 31 (28, 36) | .10 |
| Level of BCT − mm | 37 (33, 42) | 36 (33, 42) | 38 (32, 46) | .30 |
| Level of LCCA − mm | 35 (30, 39) | 34 (29, 39) | 36 (30, 39) | .47 |
| Level of LSA − mm | 33 (28, 36) | 34 (28, 40) | 32 (28, 35) | .16 |
| *Aortic lengths* | | | | |
| PLZ − mm | 42 (6, 59) | 47 (24, 61) | 22 (0, 50) | <.001 |
| STJ−BCT outer curvature − mm | 102 (86, 129) | 102 (86, 130) | 104 (86, 124) | .78 |
| STJ−BCT inner curvature − mm | 58 (46, 68) | 56 (44, 70) | 60 (49, 68) | .68 |
| STJ−LCCA outer curvature − mm | 120 (101, 143) | 120 (101, 145) | 120 (106, 135) | .55 |
| BCT−LCCA − mm | 26 (20, 32) | 27 (22, 33) | 24 (19, 31) | .26 |
| LCCA−LSA − mm | 26 (20, 33) | 27 (21, 35) | 24 (20, 29) | .11 |
| *Supra-aortic vessels* | | | | |
| Dissection of BCT | 26 (17.1) | 19 (18.8) | 7 (13.7) | .50 |
| Dissection of LSA | 27 (17.8) | 25 (24.8) | 2 (3.9) | <.001 |
| BCT diameter − mm | 15 (13, 16) | 15 (13, 16) | 14 (12, 16) | .33 |
| BCT length − mm | 37 (29, 46) | 37 (29, 46) | 37 (28, 44) | .57 |
| LSA diameter − mm | 11 (10, 12) | 11 (10, 13) | 11 (9, 12) | .11 |
| LSA length − mm | 41 (31, 48) | 41 (32, 48) | 40 (31, 48) | .19 |

Data are presented as $n$ (%), mean ± standard deviation, or median (interquartile range). AA = aortic arch; BCT = brachiocephalic trunk; LCCA = left common carotid artery; LSA = left subclavian artery; PLZ = proximal landing zone; STJ = sinotubular junction.

($n = 101$, of whom 38 [37.6%] were women), similar findings were shown, with statistically significant differences regarding the length of the PLZ (19 [0, 56] mm in women *vs.* 55 [36, 67] mm in men; $p = .010$) and the rate of LSA dissections (Supplementary Table S3). The remaining anatomical parameters showed no statistically significant differences between groups.

The impact of various potential influencing factors on the length of the PLZ in patients with a native ascending aorta was also evaluated. Univariable analysis showed a positive correlation between BSA (Spearman's ρ 0.212, 95% confidence interval [CI] 0.01 − 0.40; $p = .037$) and height (Spearman's ρ 0.306, 95% CI 0.11 − 0.48; $p = .002$) with native PLZ length. However, when subdividing patients by sex, the number of patients in each group was insufficient to show statistical significance (Supplementary Table S4; Supplementary Fig. S1). The role of the indication for surgical repair (degenerative aneurysm, post-dissection aneurysm, acute dissection, and penetrating aortic ulcer) and surgical setting (elective *vs.* urgent) on the PLZ length in patients with a native ascending aorta was also assessed. Patients undergoing repair for penetrating aortic ulcers had a statistically significantly longer median PLZ compared with those undergoing treatment of degenerative aneurysm (59 [56.9, 74.5] mm *vs.* 39.1 [0, 57] mm; $p = .009$) (Supplementary Table S5; Supplementary Fig. S2). Multivariable logistic regression analysis for the presence of PLZ $\geq$ 40 mm, including sex, height, BSA, BMI, and age, showed that increasing age (odds ratio [OR] 1.054, 95% CI 1.01 − 1.10; $p = .014$) and female sex (OR 4.85, 95% CI 1.18 − 19.88; $p = .028$) were associated with a higher risk of having an unsuitable PLZ ($<$ 40 mm).

### Feasibility analysis

Of the 152 patients, 44 (28.9%) were considered feasible for all evaluated endografts, while 82 patients (53.9%) were feasible for at least one device. Feasibility for at least one device was significantly lower in female than male patients (37.3% *vs.* 62.4%; $p = .010$). Feasibility with the Cook platform was 42.8%. Women had a tendency for lower feasibility for these devices than men (31.4% *vs.* 48.5%; $p = .056$), both for the double (31.4% *vs.* 46.5%; $p = .083$) and triple (29.4% *vs.* 38.6%; $p = .29$) branched endografts. The difference in feasibility was mainly due to the greater lack of a PLZ in female patients (32.6% *vs.* 61.9%; $p < .001$). Feasibility with the Relay platform was 40.8%, which had significantly lower feasibility in women (25.5% *vs.* 48.5%; $p = .008$). This was secondary to a decreased feasibility for the double branched endograft (25.5% *vs.* 48.5%; $p = .008$), mainly due to an unsuitable PLZ diameter (55% *vs.* 74%; $p = .011$) and length (47% *vs.* 67%; $p = .022$). Female patients also showed a tendency for lower feasibility rates for the Relay triple branched endograft, but this was not statistically significant (19.6% *vs.* 31.7%; $p = .13$). The overall decrease in feasibility for the Relay triple branched endograft in both sexes was due to the additional distance requirements between the proximal BCT and distal LSA, and with an LSA transition angle $> 75°$, with 69% of women and 60% of men meeting the distance criteria between the BCT and LSA, and 61% and 76% LSA transition angle requirements, respectively. There were no statistically significant differences between sexes regarding these additional parameters (Table 3).

There was an increased feasibility for Relay endografts compared with the Cook platform. This was mainly due to laxer length and diameter PLZ requirements (PLZ length $\geq$ 30 mm *vs.* $\geq$ 40 mm for Cook; PLZ diameter 28 − 43 mm *vs.* 24 − 38 mm for Cook). An additional five men (4.4%) and seven women (13.2%) met PLZ length requirements, while an additional 13 men (12.9%) and two women (3.9%) met PLZ diameter requirements for Relay endografts but were considered unfeasible for the Cook platform ($p < .001$). However, due to stricter IFU criteria for the Relay platform in other areas (STJ—BCT length, BCT length, distance between the proximal BCT and distal LSA, and LSA transition angle), the overall feasibility for the Relay platform ended up being slightly lower than for the Cook platform, especially for the tripe arch branch device (Table 3; Fig. 4).

### Extended feasibility criteria

A total of 64 patients (42.1%) were deemed feasible for triple arch repair according to strict IFU criteria. An additional nine patients (total $n = 73$, 48.0%) were deemed feasible with extended feasibility criteria. Of these, six had a dissected BCT, whilst three had arteria lusoria. All of these were successfully treated with additional cervical debranching (e.g., patients with arteria lusoria underwent a right carotid—subclavian bypass and plugging of the origin of the right subclavian artery) (Table 4).

### Subgroup analysis of impact of height, body mass index, body surface area, and sex on proximal landing zone length in Cook and Relay devices

In a multivariable analysis including sex, BMI, BSA, and height, only sex was identified as an independent predictor of a PLZ length $\geq$ 40 mm (OR 3.02, 95% CI 1.16 − 7.89) (Cook PLZ length requirements). Similarly, only sex showed a significant influence on the presence of a PLZ $\geq$ 30 mm (OR 1.638, 95% CI 1.217 − 1.871; $p = .041$) (Supplementary Tables S6 and S7).

## DISCUSSION

Existing literature has identified various factors that influence aortic diameter and length. Studies conducted by Redheuil *et al.*, Mirea *et al.*, and Eliathamby *et al.* have shown an age related diameter increase of the ascending aorta.[23–25] Eliathamby *et al.* further demonstrated that aortic diameter and length increase over time in both sexes, exhibiting a positive correlation with advancing age.[25] In this study, increasing age was associated with a greater risk of having an unsuitable PLZ length ($<$ 40 mm). This finding could be related to the fact that, unlike prior studies that assessed healthy individuals, this study focused on patients with underlying ascending aortic and aortic arch disease.

**Table 3.** Anatomical instruction for use criteria for the Relay and Cook double and triple branch devices, for the whole patient cohort ($n$ = 152) and according to sex.

| Criteria | Total ($n$ = 152) | Male ($n$ = 101) | Female ($n$ = 51) | $p$ value |
|---|---|---|---|---|
| *Relay double arch branch* | | | | |
| PLZ Ø 28–43 mm | 103 (67.8) | 75 (74.3) | 28 (54.9) | .011 |
| PLZ length >30 mm | 92 (60.5) | 68 (67.3) | 24 (47.1) | .022 |
| STJ–BCT outer curve >70 mm | 145 (95.4) | 97 (96.0) | 48 (94.1) | .34 |
| Aortic Ø at BCT level >20 mm | 151 (99.3) | 100 (99.0) | 51 (100) | 1.0 |
| Distance BCT–LCCA ≤45 mm | 145 (95.4) | 95 (94.1) | 50 (98.0) | .43 |
| BCT Ø ≤22 mm | 143 (94.1) | 97 (96.0) | 46 (90.2) | .16 |
| BCT length ≥25 mm | 142 (93.1) | 95 (94.1) | 47 (92.2) | .22 |
| LCCA Ø ≤22 mm | 152 (100) | 101 (100) | 51 (100) | 1.0 |
| LCCA length ≥25 mm | 152 (100) | 101 (100) | 51 (100) | 1.0 |
| All criteria | 62 (40.8) | 49 (48.6) | 13 (25.6) | .008 |
| *Relay triple arch branch (the following are additional parameters for triple Relay devices)* | | | | |
| LSA Ø ≤22 mm | 151 (99.3) | 100 (99.0) | 51 (100) | 1.0 |
| LSA length ≥25 mm | 142 (93.1) | 93 (92.1) | 49 (96.1) | 1.0 |
| Distance between Px BCT to Dx LSA | 96 (63.2) | 61 (60.4) | 35 (68.6) | .38 |
| LSA transition angle >75° | 108 (71.1) | 77 (76.2) | 31 (60.8) | .11 |
| All criteria | 42 (27.6) | 32 (31.7) | 10 (19.6) | .13 |
| *Cook double arch branch* | | | | |
| PLZ Ø 24–38 mm | 87 (57.2) | 61 (60.4) | 26 (51.0) | .30 |
| PLZ length >40 mm | 80 (52.6) | 63 (62.4) | 17 (33.3) | <.001 |
| STJ–BCT outer curve >50 mm | 151 (99.3) | 100 (99.0) | 51 (100) | 1.0 |
| BCT Ø ≤20 mm | 142 (93.4) | 96 (95.0) | 46 (90.2) | .31 |
| BCT length ≥20 mm | 146 (96.1) | 98 (97.0) | 48 (94.1) | .60 |
| LCCA Ø ≤20 mm | 152 (100) | 101 (100) | 51 (100) | 1.0 |
| All criteria | 63 (41.4) | 47 (46.5) | 16 (31.4) | .080 |
| *Cook triple arch branch (the following are additional parameters for triple Cook devices)* | | | | |
| LSA Ø ≤20 mm | 146 (96.1) | 98 (97.0) | 48 (94.1) | 1.0 |
| LSA length >20 mm | 131 (86.2) | 85 (84.2) | 46 (90.2) | .091 |
| All criteria | 54 (35.5) | 39 (38.6) | 15 (29.4) | .29 |

Data are presented as $n$ (%). PLZ = proximal landing zone; Ø = diameter; STJ = sinotubular junction; BCT = brachiocephalic trunk; LCCA = left common carotid artery; LSA = left subclavian artery; Px = proximal; Dx = distal.

Alberta *et al.*[14] reported differences in aortic arch anatomy in patients with underlying aortic disease, including acute type B aortic dissection, descending thoracic aneurysms, or traumatic injury of the descending thoracic aorta. They found that the length and diameter of the ascending aorta and arch were significant greater in patients with aortic dissection compared with aneurysmal disease.[14] However, patients included in their study had previously been

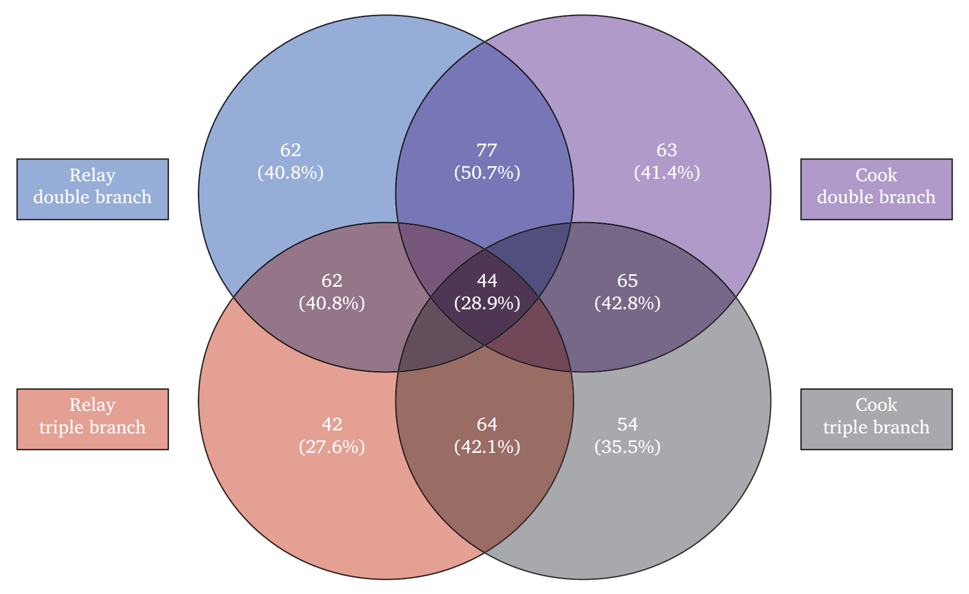


**Figure 4.** Venn diagram showing the anatomical feasibility of the four included arch branched devices.

**Table 4.** Feasibility overview for the Relay and Cook double and triple arch branch devices, according to instructions for use and with extended feasibility criteria, the whole patient cohort ($n = 152$) and according to sex.

| Feasibility | Total ($n = 152$) | Male ($n = 101$) | Female ($n = 51$) | $p$ value |
|---|---|---|---|---|
| None | 70 (46.1) | 47 (46.5) | 23 (45.1) | 1.0 |
| At least one | 82 (53.9) | 63 (62.4) | 19 (37.3) | .010 |
| At least two | 75 (49.3) | 48 (47.5) | 27 (52.9) | .41 |
| At least three | 58 (38.2) | 41 (40.6) | 17 (33.3) | .48 |
| All | 44 (28.9) | 33 (32.7) | 11 (21.6) | .19 |
| *Device specific feasibility* | | | | |
| Cook double arch branch | 63 (41.4) | 47 (46.5) | 16 (31.4) | .083 |
| Cook triple arch branch | 54 (35.5) | 39 (38.6) | 15 (29.4) | .29 |
| Relay double arch branch | 62 (40.8) | 49 (48.5) | 13 (25.5) | .008 |
| Relay triple arch branch | 42 (27.6) | 32 (31.7) | 10 (19.6) | .13 |
| *According to manufacturer* | | | | |
| Any Cook arch branch | 65 (42.8) | 49 (48.5) | 16 (31.4) | .056 |
| Any Relay arch branch | 62 (40.8) | 49 (48.5) | 13 (25.5) | .008* |
| *According to double or triple device* | | | | |
| Any double arch branch device | 77 (50.7) | 59 (58.4) | 18 (35.3) | .015* |
| Any triple arch branch device | 64 (42.1) | 48 (47.5) | 16 (31.4) | .081 |
| *Extended feasibility criteria** | | | | |
| Right carotid−subclavian bypass | 9 (5.9) | 8 (7.9) | 1 (1.9) | .27 |
| BCT dissection | 6 (3.9) | 6 (5.9) | 0 (0) | |
| Arteria lusoria | 3 (1.9) | 2 (2.0) | 1 (1.9) | |
| Total feasibility of triple devices | 86 (56.6) | 67 (66.3) | 19 (37.3) | .081 |

Data are shown as $n$ (%). BCT = brachiocephalic trunk.
* Extended feasibility criteria with the use of adjunctive procedures for feasibility to triple branched endografts.

enrolled in one of three multisite trials, had received the GORE conformable TAG device, and were required to have a proximal and distal landing zone $\geq$ 20 mm in length, with a diameter between 16 − 42 mm, so an inherent selection bias was present. In the current cohort, patients undergoing treatment for a penetrating aortic ulcer had the longest PLZ (59 mm [IQR 56.9, 74.5]), which was significantly longer than patients with degenerative aneurysms (39 mm [IQR 0, 57]) (Supplementary Table S5). The longer PLZ in this subgroup is in accordance with the more common presentation of penetrating aortic ulcers in the aortic arch and descending aorta, while being very rare in the ascending aorta.[26]

Study findings also showed a positive correlation between both height and BSA with an increasing PLZ length. Similar findings have been reported by Mirea *et al.* and Wu *et al.*, who observed an increase in the diameter and length of the ascending aorta with increasing height and BSA.[24,27] Despite this positive correlation, multivariable logistic regression analysis found increasing age (OR 1.054, 95% CI 1.01 − 1.10; $p = .014$) and female sex (OR 4.85, 95% CI 1.18 − 19.88; $p = .028$) to be associated with a higher risk of having an unsuitable PLZ (< 40 mm), but not BSA, BMI, or height. However, this study may have been underpowered in this respect.

Regarding sex related differences in aortic anatomy, Grandi *et al.* found differences in aortic diameter, target vessel orientation, and distance between the visceral vessels between female and male patients in the thoraco-abdominal aorta,[15] while Katsarou *et al.* reported larger ascending aortic and arch diameters in men compared with women.[28] Rylski *et al.* also reported a larger aortic diameter and length in men compared with women, although this changed in the ascending aorta and aortic arch after adjustment for BSA towards women.[29] In the current cohort, there were no statistically significant differences regarding the diameters and lengths of the ascending aorta, aortic arch, and or supra-aortic vessels. Despite this, the length of the PLZ in female patients was significantly shorter than in male patients, even though the distribution of indications for surgical repair was similar in both groups. This could have been secondary to a more complex disease morphology in women, as found in other aortic sections.[30] Multivariable regression confirmed female sex to be an independent predictor of non-suitability to a PLZ $\geq$ 40 mm.

Both sexes presented feasibility rates for at least one endograft to be around 50 − 55%, without statistically significant differences between groups. These findings were consistent with the results of sex independent studies that have reported anatomical feasibility rates between 40 − 50%.[6,18] Furthermore, similar to prior literature, the length and diameter of the PLZ were the main limiting factors for arch branched device feasibility.[6,18,23−25] In this study, although more men met the PLZ length and diameter criteria than women, this did not translate into increased overall feasibility. This could have been due to an insufficient sample size of the included cohort. Despite not finding statistically significant differences for the feasibility of at least one endograft, men presented a tendency for higher feasibility rates for the Cook platform (48.5% *vs.* 31.4%; $p = .056$), although feasibility rates for the triple arch branched device fell in men due to a higher rate of LSA dissections. Left subclavian artery characteristics as a responsible factor for non-feasibility have also been reported previously in around 10% of patients by Spanos *et al.*[31] Female patients had a significantly lower feasibility for the Relay platform (48.5% *vs.* 25.5%; $p = .008$), mainly secondary to the PLZ diameter and length requirements. Finally, the triple branched Relay device was the endograft with the lowest feasibility (27.6% in the general cohort; 31.7% in men *vs.* 19.6% in women, $p = .13$). This was due to the additional requirement of (1) a distance between proximal BCT to distal LSA $< 65$ mm, which was only met by 60% of men and 69% of women; and (2) an LSA transition angle $> 75^\circ$, met by 77% of men and 64% of women.

This study presents the first results of the feasibility evaluation of endovascular branched arch treatment with a sex specific analysis. In accordance with the prior literature, the PLZ appeared to be the most determining factor for endograft suitability. PLZ diameter and length showed sex related differences, resulting in an increased suitability for male patients. Device manufacturers could try to adjust endograft diameter availability to accommodate more patients. Regarding the length of the PLZ, this may be much more difficult owing to the risk of sealing failure (endoleak type Ia). Furthermore, despite laxer PZL diameter and length requirements, the triple arch branched Relay device was the endograft assessed with the lowest feasibility, mainly due to distance requirements between the supra-aortic vessels and LSA transition angle. If criteria for both of these parameters were broadened, feasibility for this endograft would be considerably increased.

### *Limitations*

Several important limitations of this study should be discussed, including its retrospective nature. Due to unavailable or poor quality CTAs, 22.1% of the initial population was excluded, mainly affecting patients undergoing open arch repair (45.1%), in contrast to those undergoing endovascular repair (3.0%). Of patients undergoing open repair, excluded due to insufficient imaging, 42.2% were female and 57.8% were male, so that the proportion of women without available CTAs was slightly higher than that included in the study (33.6%). This could have led to selection bias, resulting in an over or underestimation of the overall and sex based feasibility rates. As previously explained in the methodology, measurements were performed by one investigator (D.B.), validated by another (C.F.P.), and, in case of disagreements, re-assessed by a third (N.T.). In the end, one set of measurements was available; therefore, statistical interobserver variability analysis could not be performed. This could have led to an intrinsic measurement error in some cases, although given that all cases were assessed by at least two investigators, the possibility of this error was low. Furthermore, all lengths and diameters were measured by investigators from the same unit, following certain guidance (outer to outer including all of the wall in a zoomed in image, correction of the centreline). It is possible that if these cases had been measured by a different unit, which used a slightly different way of measuring complex cases, there would have been some variation.

The small number of patients and the difference in sample size between male and female groups might have influenced the statistical results regarding significance. Furthermore, only the Cook and Relay platforms were included, potentially leading to an industry based bias. Additionally, fenestrated endovascular solutions were not considered, as *a priori* most of the included patients would have required a more proximal repair. Finally, evaluation of access vessel anatomy was not performed; this could have led to even lower feasibility, specifically in female patients with smaller access vessels, given the need for larger introducer sheaths (25 − 26 Fr). However, most access vessel limitations can be overcome with the use of an iliofemoral conduit or other adjunctive measures.

### *Conclusion*

Although most ascending aortic and arch parameters showed similar trends in both sexes, the availability of a suitable PLZ was lower in female patients. Proximal landing zone anatomical requirements were the main determining factor of feasibility for all assessed endografts and both sexes. As the availability of a suitable PLZ was lower in female patients, women presented with significantly lower feasibility rates for double arch branched endografts and, to a lesser extent, triple arch branched endografts. Triple branched endografts recorded lower feasibility for both sexes due to additional requirements.

## CONFLICT OF INTEREST

N.T. is a consultant for Cook Medical and receives speaking fees from Bentley.

## FUNDING

No funding was obtained for this study.

## APPENDIX A. SUPPLEMENTARY DATA

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ejvs.2024.06.012.

## REFERENCES

1 Upchurch GR, Perry RJ. Thoracic and thoracoabdominal aortic aneurysm and dissections: etiology, natural history, medical management and decision making. In: *Rutherford's Vascular and Endovascular Therapy (Sidawy AN, Perler BA, eds)*, Vol. 1. Philadelphia, PA: Elsevier Inc., 2019;3266−324.

2 Czerny M, Schmidli J, Adler S, van den Berg JC, Bertoglio L, Carrel T, et al. Editor's choice − Current options and recommendations for the treatment of thoracic aortic pathologies involving the aortic arch: an expert consensus document of the European Association for Cardio-Thoracic Surgery (EACTS) & the European Society for Vascular Surgery (ESVS). *Eur J Vasc Endovasc Surg* 2019;**57**:165−98.

3 Tadros R, Safir SR, Faries PL, Han DK, Ellozy S, Chander RK. Hybrid repair techniques for complex aneurysm and dissections involving the aortic arch and thoracic aorta. *Surg Technol Int* 2017;**30**:243−7.

4 Antoniou GA, El Sakka K, Hamady M, Wolfe JH. Hybrid treatment of complex aortic arch disease with supra-aortic debranching and

endovascular stent graft repair. *Eur J Vasc Endovasc Surg* 2010;**39**:683–90.

5 Haulon S, Greenberg RK, Spear R, Eagleton M, Abraham C, Lioupis C, et al. Global experience with an inner branched arch endograft. *J Thorac Cardiovasc Surg* 2014;**148**:1709–16.

6 Smorenburg SPM, Montesano M, Hoogteijling TJ, Truijers M, Symersky P, Jansen EK, et al. Anatomic suitability for branched thoracic endovascular repair in patients with aortic arch pathological features. *J Am Heart Assoc* 2020;**9**:e016695.

7 Spanos K, Tsilimparis N, Rohlffs F, Wipper S, Detter C, Behrendt C-A, et al. Total endovascular arch repair is the procedure of the future. *J Cardiovasc Surg (Torino)* 2018;**59**:559–71.

8 Gao JP, Guo W, Zhang HP. Incidence and prognostic associations of early postoperative stroke and death among patients undergoing inner branched thoracic endovascular repair of aortic arch pathologies: a systematic review and meta-analysis. *J Endovasc Ther* 2023. doi: 10.1177/15266028231187715 [epub ahead of print].

9 Jakob HG. Repair of aortic arch disease is undergoing a dramatic change within the next years. *J Cardiovasc Surg (Torino)* 2018;**59**:538–9.

10 Chung J, Coutinho T, Chu MWA, Ouzounian M. Sex differences in thoracic aortic disease: a review of the literature and a call to action. *J Thorac Cardiovasc Surg* 2020;**160**:656–60.

11 Smedberg C, Steuer J, Leander K, Hultgren R. Sex differences and temporal trends in aortic dissection: a population-based study of incidence, treatment strategies, and outcome in Swedish patients during 15 years. *Eur Heart J* 2020;**41**:2430–8.

12 Lodewyks CL, Prior HJ, Hiebert BM, Nickel NC, Yamashita MH, Ouzounian M, et al. A province-wide analysis of the epidemiology of thoracic aortic disease: incidence is increasing in a sex-specific way. *Can J Cardiol* 2020;**36**:1729–38.

13 Boufi M, Guivier-Curien C, Loundou AD, Deplano V, Boiron O, Chaumoitre K, et al. Morphological analysis of healthy aortic arch. *Eur J Vasc Endovasc Surg* 2017;**53**:663–70.

14 Alberta HB, Takayama T, Smits TC, Wendorff BB, Cambria RP, Farber MA, et al. Aortic arch morphology and aortic length in patients with dissection, traumatic and aneurysmal disease. *Eur J Vasc Endovasc Surg* 2015;**50**:754–60.

15 Grandi A, Carta N, Cambiaghi T, Bilman V, Melissano G, Chiesa R, et al. Sex-related anatomical feasibility differences in endovascular repair of thoracoabdominal aortic aneurysms with a multibranched stent-graft. *J Endovasc Ther* 2021;**28**:283–94.

16 Von Elm A, Altman DG, Egger M, Pocock SJ, Gotzsche PC, Vandenbroucke JP. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. *Lancet* 2007;**370**:1453–7.

17 DeRango P. What we can learn from experts and expertise with fenestrated and branched stent grafts: the "croissant–doughnut" concept for post-dissection aneurysm repair. *Eur J Vasc Endovasc Surg* 2016;**4**:498.

18 Benfor B, Prendes CF, Peterss S, Stavroulakis K, Stana J, Pichlmaier M, et al. Anatomical analysis of the aortic arch and feasibility study of double and triple branched thoracic endografts in the treatment of isolated arch pathologies. *Eur J Cardiothorac Surg* 2022;**62**:ezac246.

19 Alhafez BA, Van Thi Thanh T, Ocazionez D, Sohrabi S, Sandhu H, Estrera A, et al. Aortic arch tortuosity, a novel biomarker for thoracic aortic disease, is increased in adults with bicuspid aortic valve. *Int J Cardiol* 2019;**284**:84–9.

20 Fujimura N, Ichihashi S, Motoki M, Ohtsubo S, Kawauchi Y, Kichikawa K, et al. Anatomical analysis and feasibility study of next-generation fenestrated or branched stent-grafts for the treatment of arch aneurysms. *J Endovasc Ther* 2020;**27**:777–84.

21 Torrealba JI, Spanos K, Panuccio G, Rohlffs F, Gandet T, Heidemann F, et al. Non-standard management of target vessels with the inner branch arch endograft: a single-center retrospective study. *J Endovasc Ther* 2022;**29**:555–64.

22 Konstantinou N, Peterss S, Stana J, Rantner B, Banafsche R, Pichlmaier M, et al. Passing a mechanical aortic valve with a short tip dilator to facilitate aortic arch endovascular branched repair. *J Endovasc Ther* 2021;**28**:388–92.

23 Redheuil A, Yu WC, Mousseaux E, Harouni AA, Kachenoura N, Wu CO, et al. Age-related changes in aortic arch geometry: relationship with proximal aortic function and left ventricular mass and remodeling. *J Am Coll Cardiol* 2011;**58**:1262–70.

24 Mirea O, Maffessanti F, Gripari P, Tamborini G, Muratori M, Fusini L, et al. Effects of aging and body size on proximal and ascending aorta and aortic arch: inner edge-to-inner edge reference values in a large adult population by two-dimensional transthoracic echocardiography. *J Am Soc Echocardiogr* 2013;**26**:419–27.

25 Eliathamby D, Gutierrez M, Liu A, Ouzounian M, Forbes TL, Tan KT, et al. Ascending aortic length and its association with type a aortic dissection. *J Am Heart Assoc* 2021;**10**:e020140.

26 Isselbacher EM, Preventza O, Black JH 3rd, Augoustides JG, Beck AW, Bolen MA, et al. 2022 ACC/AHA guideline for the diagnosis and management of aortic disease: a report of the American Heart Association/American College of Cardiology Joint Committee on Clinical Practice Guidelines. *Circulation* 2022;**146**:e334–482.

27 Wu J, Zafar MA, Li Y, Saeyeldin A, Huang Y, Zhao R, et al. Ascending aortic length and risk of aortic adverse events: the neglected dimension. *J Am Coll Cardiol* 2019;**74**:1883–94.

28 Katsarou M, Mandigers TJ, Berczeli M, Mujeeb Zubair M, Belvroy VM, Bissacco D, et al. Sex-specific morphometric analysis of ascending aorta and aortic arch for planning thoracic endovascular aortic repair: a retrospective cohort study. *J Endovasc Ther* 2023. doi: 10.1177/15266028231210228 [epub ahead of print].

29 Rylski B, Desjardins B, Moser W, Bavaria JE, Milewski RK. Gender-related changes in aortic geometry throughout life. *Eur J Cardiothorac Surg* 2014;**45**:805–11.

30 De Freitas S, Falls G, Weis T, Bakhshi K, Korepta LM, Bechara CF, et al. Comprehensive framework of factors accounting for worse aortic aneurysm outcomes in females: a scoping review. *Semin Vasc Surg* 2023;**36**:508–16.

31 Spanos K, Pannucio G, Rohlffs F, Heidemann F, Tsilimparis N, Kölbel T. Technical aspects of branched thoracic arch graft implantation for aortic arch pathologies. *J Endovasc Ther* 2020;**27**:792–800.