Contemporary comparison of aortic arch repair by endovascular and open surgical reconstructions

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Objective: **This study analyzed total aortic arch reconstruction in a contemporary comparison of current open and endovascular repair.**

Methods: **Endovascular (group 1) and open arch procedures (group 2) performed during 2007 to 2013 were entered in a prospective database and retrospectively analyzed. Endovascular repair (proximal landing zones 0-1), with or without a hybrid adjunct, was selected for patients with a high comorbidity profile and fit anatomy. Operations involving coverage of left subclavian artery only (zone 2 proximal landing: n = 41) and open hemiarch replacement (n = 434) were excluded. Early and midterm mortality and major complications were assessed.**

Results: **Overall, 100 (78 men; mean age, 68 years) consecutive procedures were analyzed: 29 patients in group 2 and 71 in group 1. Seven group 1 patients were treated with branched or chimney stent graft, and 64 with partial or total debranching and straight stent graft. The 29 patients in group 2 were younger (mean age, 61.9 vs 70.3; $P = .005$), more frequently females (48.2% vs 11.3; $P < .001$) with less cardiac (6.9% vs 38.2%; $P = .001$), hypertensive (58.5% vs 88.4%; $P = .002$), and peripheral artery (0% vs 16.2%; $P = .031$) disease. At 30 days, there were six deaths in group 1 and four in group 2 (8.5% vs 13.8%; odds ratio, 1.7; 95% confidence interval, 0.45-6.66; $P = .47$), and four strokes in group 1 and one in group 2 (odds ratio, 0.59; 95% confidence interval, 0.06-5.59; $P = 1$). Spinal cord ischemia occurred in two group 1 patients and in no group 2 patients. Three retrograde dissections (1 fatal) were detected in group 1. During a mean follow-up of 26.2 months, two type I endoleaks and three reinterventions were recorded in group 1 (all for persistent endoleak), and one reintervention was performed in group 2. According to Kaplan Meier estimates, survival at 4 years was 79.8% in group 1 and 69.8% in group 2 ($P = .62$), and freedom from late reintervention was 94.6% and 95.5%, respectively ($P = .82$).**

Conclusions: **Despite the older age and a higher comorbidity profile in patients with challenging aortic arch disease suitable and selected for endovascular arch repair, no significant differences were detected in perioperative and 4-year outcomes compared with the younger patients undergoing open arch total repair. An endovascular approach might also be a valid alternative to open surgery in average-risk patients with aortic arch diseases requiring 0 to 1 landing zones, when morphologically feasible. However, larger concurrent comparison and longer follow-up are needed to confirm this hypothesis. (J Vasc Surg 2015;61:339-46.)**

In recent decades, open repair of the aortic arch has been advantaged by progressive improvements and adjuncts that conferred the achievement of safer outcomes and reduced mortality.[1,2] At the same time, hybrid or total endovascular repair has been increasingly used as an alternative in patients previously denied surgery because of relevant comorbidities.[3,4] Nevertheless, hybrid arch procedures, despite the reduced invasiveness and the progressive evolution in recent years, present unclear benefits in the outcome, and total endovascular repair is still in its early days.[5-7] Particularly for diseases involving total arch and requiring stent graft implantation in the ascending aorta (zone 0), perioperative mortality and stroke risks are less than satisfying.[8-15] The requirement of anatomic feasibility is an additional constraint that does not always allow the implementation of these new approaches. Still, any type of aortic arch repair requiring revascularization of supra-aortic vessels remains demanding and exposes the patient to not negligible mortality and stroke risks.

The aim of this study was to investigate the early-term and midterm outcome of aortic arch repairs in a concurrent series of patients treated with different modalities of endovascular and open surgery procedures.

METHODS

The study was based on retrospective analysis of prospectively collected data, and Institutional Review Board approval was not required according to local Ethical Committees preconditions. All patients gave informed consent before their interventional procedure.

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Data from all consecutive patients who underwent endovascular repair, with or without a hybrid adjunct, for aortic diseases involving the aortic arch from 2007 to 2013 at two vascular centers (Unit of Vascular Surgery, Hospital S. Camillo-Forlanini, Rome, and Unit of Vascular and Endovascular Surgery, Hospital S. Maria della Misericordia, University of Perugia, Perugia, Italy) were collected in a cumulative database and analyzed as group 1.

To avoid confounding factors due to major variability in surgical techniques, open arch repairs performed electively at one of the two centers were used as controls. Thereby, data for consecutive conventional total arch open surgery performed during the same period at one of the two centers (Unit of Cardiac Surgery, Hospital S. Camillo-Forlanini, Rome, Italy) were entered in the same database and examined as the control group (group 2) for this study.

Only hybrid/endovascular repairs involving stent graft coverage of the innominate artery or left common carotid artery (LCCA) landing in zone 0 or in zone 1 (according to Ishimaru[16]) were included. Thoracic stent grafts deployed distally, in zones 2 or 3, or endovascular completion after total arch replacement (elephant trunk) were excluded. Open repairs not requiring total arch replacement and acute type A dissections treated as an emergency were also excluded.

Determination of the type of repair was at the discretion of the surgeon. In general, endovascular or hybrid strategies were preferred for anatomically suitable and poor surgical candidates. Open surgery was offered to younger patients and for complex aortic arch diseases unfit for stent graft landing. A proximal landing zone of healthy aorta, at least 2 cm in length and <42 mm in diameter, based on multiplanar reconstructions of preoperative computed tomography angiography (CTA) scans, was required for endovascular repair.

Patients were followed up with regular postoperative appointments. The stability of the endovascular repair was monitored yearly with contrast CTA. Assessment of survival was completed by phone interview. Median follow-up was 23.4 months (mean, 27.9 months; interquartile range [IQR], 37.8 months).

The primary outcome of this study was perioperative mortality. Additional outcomes included perioperative stroke, spinal cord ischemia and complications, and all-cause survival at 4 years. Perioperative outcomes were recorded ≤30 days of surgery or in the hospital if occurring during a hospitalization that was protracted >30 days.

Aortic morphology of open surgical repairs was reviewed according to preoperative CTA scans, and the feasibility for an endovascular approach was tested in the open group as a secondary outcome measure.

All CTA images were evaluated using the dedicated Aquarius iNtuition software (TeraRecon, San Mateo, Calif).

Statistical analysis. Continuous and categoric variables were compared between groups using one-way analysis of variance and the χ^2 test. Survival and freedom from reintervention related to aortic repair was estimated using the Kaplan-Meier method. For patients who underwent staged repair, the date of the completion procedure was used to calculate survival. The probability of receiving open or endovascular treatment for arch repair based on the observed baseline covariates was tested using the propensity score from a nonparsimonious logistic regression model. Calculations were performed using SPSS software (SPSS, Chicago, Ill).

Operative technique for endovascular repair. In hybrid procedures for zone 0 landing, all supra-aortic vessels were revascularized through a median sternotomy with cervical extension of the incision cephalad to the left, allowing exposure of the supra-aortic trunks, and subsequent bypass from the ascending aorta to the individual vessels. For zone 1 landing, a carotid-to-carotid bypass using cervical incisions and retropharyngeal or antetracheal tunnel was performed in association with left subclavian artery (LSA) revascularization by transposition or bypass. The subclavian arteries were always revascularized, except in emergency cases. The LSA stump was occluded through oversewing, clipping, or endovascular plug or coils. Debranching was performed simultaneously or staged.

Branched stent grafting was associated with LCCA-to-LSA bypass with the above-described technique. The chimney technique was used in urgent cases or when a branched stent graft was not available.

Stent grafts were deployed retrograde through femoral access or by conduit for common iliac arteries in case of small access vessels. Different thoracic stent grafts available during the study period were used for thoracic endovascular aortic repair (TEVAR) and included Gore TAG and C-TAG (W. L. Gore & Associates, Flagstaff, Ariz), Talent and Valiant (Medtronic, Santa Rosa, Calif), Zenith TX2 and Alpha (Cook Inc, Bloomington, Ind), and Relay (Bolton Medical, Sunrise, Fla). Right subclavian and left carotid arteries (LSA when needed in total chimney) were accessed through a cervical cutdown to introduce a covered stent. Covered stents used for supra-aortic trunks were the Excluder iliac leg and Viabahn (W. L. Gore &Associates), Endurant iliac leg (Medtronic), or the Fluency (Bard Peripheral Vascular, Tempe, Ariz). Branched stent grafts for supra-aortic vessels revascularization included customized stent grafts by Bolton Medical.

All endovascular procedures were performed under cerebral flow monitoring using cerebral oximetry and fast cardiac pacing during deployment of the thoracic stent graft. Balloon inflation was never used in the aortic arch.

Preoperative cerebrospinal fluid drainage to prevent spinal cord ischemia was selectively used, based on length of coverage in thoracoabdominal aorta.

Surgical procedures for conventional total arch replacement. Cardiopulmonary bypass was established with cannulation of the right axillary artery and the right atrium directly or through the right femoral vein. Patients were cooled to a core temperature of 20°C to 22°C. Antegrade selective cerebral perfusion was used (flow, 10-15 mL/kg/min). In most cases, a collagen-impregnated

Table I. Baseline characteristics in 71 patients undergoing endovascular arch repair and 29 patients undergoing open arch repair[a]

Characteristics[b]	*Endovascular (group 1) (n = 71)*	*Open (group 2) (n = 29)*	*OR (95% CI)*	P *value*
Age, years	70.3 ± 9.3 (39-84)	61.9 ± 14 (24-77)		.005
Males	63 (88.7)	15 (51.7)	0.14 (0.05-0.38)	<.001
Arch atherosclerotic aneurysm	33 (46.5)	24 (82.7)		
Dissection	16 (22.5)	3 (10.3)		
Chronic	15 (21.1)	3 (10.3)		
Type A	8 (11.3)	3 (10.3)		
Type B	7 (9.8)	0 (0)		
Acute				
Type B	1 (1.4)	0 (0)		
Penetrating aortic ulcer	6 (8.5)	0 (0)		.17
Pseudoaneurysm	2 (2.8)	2 (6.9)	2.56 (0.34-19.07)	.58
Aberrant subclavian aneurysm	7 (9.9)	0 (0)		
Post-traumatic aneurysm	2 (2.8)	0 (0)		1
Rupture	5 (7)	0 (0)		.31
Urgent repair	7 (9.9)	0 (0)		.1
Anatomic variants	16 (22.5)	1 (3.4)		
Bovine	6 (8.5)	0 (0)		
Right-sided	2 (2.8)	0 (0)		
Aberrant subclavian	8 (11.2)	1 (3.4)		
Prior aortic surgery	16 (22.5)	3 (10.3)		
Ascending aorta	8 (11.2)	3 (10.3)		
Abdominal aorta	8 (11.2)	0 (0)		
Hypertension	61 (88.4)	17 (58.6)	0.18 (0.06-0.53)	.002
Diabetes	11 (15.9)	3 (10.3)	0.61 (0.16-2.36)	.54
COPD	20 (29)	5 (17.2)	0.51 (0.17-1.53)	.31
Renal insufficiency	5 (7.2)	0 (0)		.31
Coronary artery disease	26 (38.2)	2 (6.9)	0.12 (0.03-0.55)	.001
Hyperlipidemia	36 (52.2)	12 (41.4)	0.65 (0.27-1.55)	.38
Peripheral arterial disease	11 (16.2)	0 (0)		.031

CI, Confidence interval; *COPD,* chronic obstructive pulmonary disease; *OR,* odds ratio.

[a] Comorbid conditions were defined using The Society of Thoracic Surgeons definitions (www.sts.org).

[b] Categoric data are shown as number (%) and age is presented as mean ± standard deviation (range).

presewn multibranched Gelweave graft (Vascutek Terumo, Renfrewshire, UK) was first anastomosed to the mobilized and divided descending thoracic aorta. The LSA, the LCCA, and the innominate arteries were then anastomosed to the three adjacent branches of the aortic graft. After evacuation of air, the clamp was positioned proximally in the graft, and antegrade flow was established through all three brachiocephalic arteries and to the distal aorta through the right axillary artery. Once the arch and distal aortic anastomoses were completed, the proximal anastomosis of the aortic graft to the ascending aorta was performed. The elephant trunk technique was used in patients affected by extensive thoracic aneurysms that involved the ascending, arch, and descending segments.

Aortic valve or root replacement and coronary artery bypass grafting, if indicated, were done at this time. Cardiopulmonary bypass was discontinued once rewarming was completed.

RESULTS

During the study period, 546 procedures involving the aortic arch were identified. We excluded 41 patients undergoing endovascular repair involving zone 2 and 434 with open repair not involving the entire aortic arch, leaving 100 patients representing the present study population. Of these, 71 in group 1 underwent endovascular repair, with or without a hybrid adjunct, and 29 in group 2 concurrently underwent open surgery for total arch repair.

The patients (78% males) were a mean age of 67.8 years (range, 24-84 years). Demographics and baseline characteristics of both groups are reported in Table I. Indications for treatment were degenerative aneurysm, chronic dissection, penetrating ulcer, aortic arch pseudoaneurysm, or aberrant subclavian (only in group 1), as reported in Table I. Cerebrospinal fluid drainage was used in three patients (4.2%) in group 1 because of extensive aortic coverage or previous abdominal aortic surgery but never in group 2.

Six patients in the endovascular group were urgently treated for impending aortic rupture. All procedures in group 2 were performed electively.

Among the 71 procedures in group 1, 41 were staged, and 23 required proximal landing in zone 0. Repairs for zone 1 (n = 48) were performed using extrathoracic bypass with a different extension, as detailed in Table II. For repairs with zone 0 landing, total surgical debranching was required in 16, and a combination of surgical and endovascular procedures (branched or chimney stent grafts) was used in the remaining seven. Four of these were totally endovascular. Technical details are reported in Table II.

Table II. Technical details in 71 endovascular procedures

Technical details	*No. (%)*	*Procedure description*
Staged procedure	41 (57.7)	
Zone 0	23 (32.4)	16 total surgical debranching 1 single-chimney stent graft + carotid-carotid-LSA[a] 1 double-chimney stent graft (LSA covered in previous TEVAR) 2 triple-chimney stent graft 1 single-branched stent graft + carotid-carotid-LSA[a] 2 double branched stent graft + carotid-subclavian[b]
Zone 1	48 (67.6)	Surgical bypass/transposition 36 carotid-carotid-subclavian[a] (20 retropharyngeal; 16 antetracheal) 1 carotid-carotid[c] (antetracheal) 6 carotid-subclavian[b] (bovine arch) 5 bilateral carotid-subclavian[b] (aberrant subclavian)

LSA, Left subclavian artery; *TEVAR,* thoracic endovascular aortic repair.

[a] Right common carotid-left common carotid-LSA surgical bypass/transposition.

[b] Common carotid-subclavian surgical bypass/transposition.

[c] Right common carotid-left common carotid surgical bypass. In two patients, the LSAs were not revascularized because of urgency or direct vertebral revascularization.

In group 2, the mean clamping time was 95 minutes, and extracorporeal circulation time was 168 minutes. Two additional coronary artery bypass grafts and three aortic valve replacements were required in four patients.

The probability that a patient would receive one or an alternative repair conditional to the observed baseline characteristics (age, sex, hypertension, renal insufficiency, diabetes, respiratory disease, coronary/cardiac heart disease, peripheral artery disease, dissection, aortic ulcer, aneurysm diameter, abdominal aortic aneurysm) was analyzed using propensity score. Patients undergoing open surgery were younger (age, odds ratio [OR], 0.8; 95% confidence interval [CI], 0.76-0.94; $P = .002$) and less likely to be women (OR, 0.05; 95% CI, 0.010-0.27; $P < .0001$) or to have a history of coronary/cardiac heart disease (OR, 0.12; 95% CI, 0.02-0.82; $P = .03$).

Perioperative results. Perioperative results are reported n Table III. There were 10 deaths, five strokes, and two patients with persisting spinal cord ischemia at 30 days. Six deaths in group 1 were due to stroke ($n = 2$), respiratory insufficiency ($n = 2$), myocardial infarction ($n = 1$), and acute retrograde dissection ($n = 1$) that occurred early after total surgical debranching in a patient waiting for completion with TEVAR. Four deaths in group 2 were due to one patient each with cardiac failure after prolonged extracorporeal membrane oxygenator assistance, right ventricular failure, massive hemorrhage, and cardiac rupture.

In the endovascular group, two additional retrograde dissections occurred: one during total debranching surgery and the other at 10 days after partial debranching and TEVAR. Both were successfully treated with ascending aorta replacement at diagnosis. In one of these two patients, the CTA scan after ascending aorta replacement revealed an asymptomatic occlusion of a carotid-to-carotid bypass. One additional asymptomatic occlusion of a carotid-to-carotid bypass, recorded 6 days after surgery, was repaired with redo bypass. Three type I endoleaks were detected perioperatively in group 1. Two of these three were gutter endoleaks (ie, secondary to the channels between the chimney and the aortic stent graft). All were managed with early reintervention using embolization ($n = 2$) or proximal stent graft extension ($n = 1$). Also observed were one patient with phrenic nerve damage, two patients with Bernard-Horner syndrome after partial debranching surgery, and two iliac ruptures after a TEVAR procedure.

In the open group, two patients with major perioperative bleeding and two with sternal wound dehiscence required redo surgery.

Late results. Late results were assessed at a similar length median follow-up in both groups (23.1 [IQR, 31.6] months for group 1 and 26.6 [IQR, 45.3] months for group 2; $P = .45$).

All-cause survival at 4 years was 79.8% in group 1 and 69.8% in group 2 ($P = .62$; Fig 1). In group 1, there were two aorta-related late deaths, both secondary to persistent proximal type I endoleak. The first occurred after late aortic arch rupture at 28 months in a patient with a single chimney stent graft on the innominate artery complicated by gutter endoleak refractory to multiple embolization procedures. The second occurred as a result of cardiac tamponade during redo intervention (branched stent graft) at 50 months in a patient with late reperfusion of the aneurysm due to proximal extension of the disease. One of the four late deaths in group 2 was secondary to abdominal aortic aneurysm rupture.

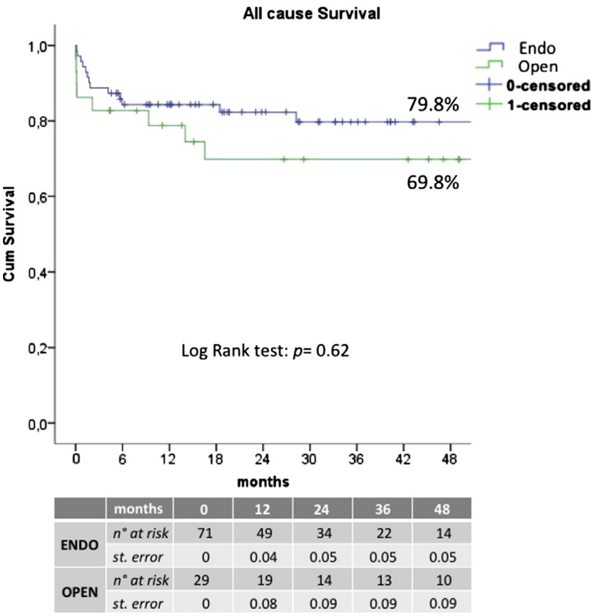
During follow-up, three reinterventions were performed in group 1 and one in group 2. In the endovascular group, one patient underwent successful gutter endoleak embolization and two patients needed zone 1 to zone 0 extensions (one chimney and one branched stent graft). Sternal redo surgery was required for infection in a patient 6 months after open surgery. Freedom from reintervention at 4 years was 94.6% in group 1 and 95.5% in group 2 ($P = .82$; Fig 2).

Morphology feasibility. To analyze morphology feasibility, CTA review was restricted to the 79 patients referred to one of the two study centers where both techniques were performed (29 open and 50 endovascular) during the same interval for homogeneity of data. Preoperative aortic CTA scans performed ≤1 month before scheduled open surgery were reviewed. Feasibility criteria for endovascular repair (at least 2 cm in length and <42-mm proximal landing zone) were identified in five of the 29 patients (17%) receiving open arch surgery in that center. Among the 79 open and endovascular arch reconstructions

Table III. Perioperative results in 100 patients

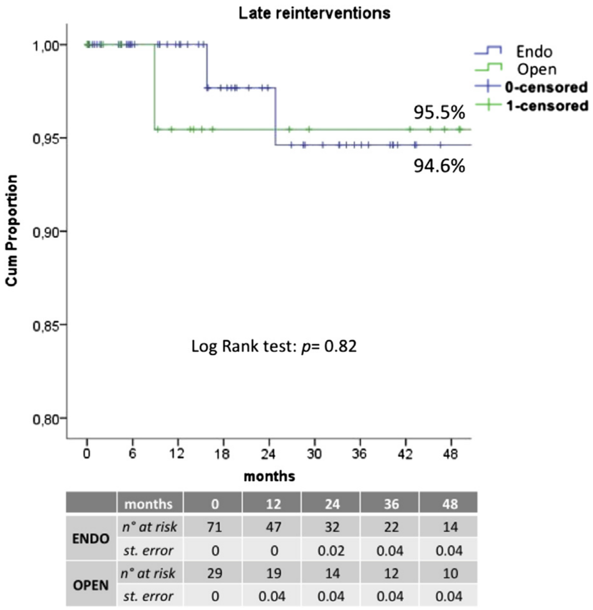
Outcomes	*Total, No. (%)*	*Endovascular (group 1), No. (%)*	*Open (group 2), No. (%)*	*OR (95% CI)*	P *value*
Death	10 (10)	6 (8.5)	4 (13.8)	1.73 (0.45-6.66)	.47
Stroke	5 (5)	4 (5.6)	1 (3.4)	0.6 (0.06-5.59)	1
Stroke/death	13 (13)	8 (11.3)	5 (17.2)	1.64 (0.49-5.51)	.51
Spinal cord ischemia	2 (2)	2 (2.8)	0 (0)		.5
Retrograde dissection	3 (3)	3 (4.2)	—		
Type I endoleak	3 (3)	3 (4.2)	—		
Bleeding	2 (2)	0 (0)	2 (6.9)		
Wound dehiscence	2 (2)	0 (0)	2 (6.9)		

CI, Confidence interval; *OR,* odds ratio.



	months	0	12	24	36	48
ENDO	*n° at risk*	71	49	34	22	14
	st. error	0	0.04	0.05	0.05	0.05
OPEN	*n° at risk*	29	19	14	13	10
	st. error	0	0.08	0.09	0.09	0.09

Fig 1. Survival after endovascular (*blue line*) and open (*green line*) arch repair.



	months	0	12	24	36	48
ENDO	*n° at risk*	71	47	32	22	14
	st. error	0	0	0.02	0.04	0.04
OPEN	*n° at risk*	29	19	14	12	10
	st. error	0	0.04	0.04	0.04	0.04

Fig 2. Freedom from aortic arch related reinterventions after endovascular (*blue line*) and open (*green line*) arch repair.

performed at the center, 55 (69.6%) were morphologically suitable for endovascular repair.

DISCUSSION

This study focused on current data from a contemporary series of endovascular and open approaches to understand ongoing results from repair of the most challenging arch diseases; therefore, we selected only endovascular repairs requiring zones 0 and 1 landing and total arch open repair performed in the last 7 years. Even though different surgical techniques were used (with or without adjuncts of coronary bypass and valve replacement), our open group would reflect outcomes in a common series of consecutive patients undergoing open aortic repair requiring total arch replacement. Similarly, different endovascular or hybrid techniques were applied in the endovascular group to encompass all of the potentially best technologic options available today for less-invasive alternative approach to the arch.

Our data confirmed, as suggested by others, a similar perioperative stroke/death rate between endovascular and open arch surgery when the procedures were applied to properly selected patients. Following best suitability criteria for each procedure, not significant lower 30-day mortality (8.5% vs 13.8%) and not significant higher stroke risks (5.6% vs 3.4%) were found in the endovascular group. Milewski et al[11] similarly reported a comparative series of 27 elective open arch debranching and 45 conventional open total arch reconstructions and found no significant differences in in-hospital mortality, 11% in the hybrid and 16% in the open arch repair cohort.

Despite the large number of studies published on arch repair, the variability in endovascular arch techniques, including less invasive or more invasive hybrid adjuncts, such as aortic partial occluding clamp or cross-clamping associated or not with ascending aorta replacement or cardiac revascularization, decreases the consistency of literature results for zones 0 to 1 arch repairs.[17-20] Most of the series including a historical open surgical cohort or endovascular repairs requiring stent graft landing distally or at the origin of LSA (ie, partial arch coverage in zones 3 or 2), with misleading comparison of data.[4] The disparity in analyses for arch populations is even more evident in studies matching open and endovascular arch approaches, due to large variability in selecting the open arch techniques.[2,10-15] The meta-analysis of Benedetto et al[15] of four comparative arch studies (hybrid vs open) concluded there was a not significantly lower pooled perioperative mortality (OR, 0.67; 95% CI, 0.27-1.63) and higher pooled stroke risk (OR, 1.93; 95% CI, 0.11-17.1) for the hybrid arch group. However, the heterogeneity in the case mix, the extension of the diseases, and the limited numbers available for quantitative analysis (109 hybrid, 269 open) did not allow the authors to achieve any strong conclusion on the best treatment strategy for arch pathology.[15] A number of different factors may preclude the use of endovascular (eg, aortic diameter) or open surgery (eg, high comorbid profile, old age) for aortic arch repair. An individualized approach is required to obtain the best results with one or the other option.

Patient age is the most commonly used selection criteria to approach the zones 0 to 1 arch, with older patients generally directed to endovascular repair. Milewski et al[11] reported a significant and four-times lower mortality in patients aged <75 years (9%) compared with patients aged >75 years (36%; $P < .05$) in the open arch group. Accordingly, our open surgery patients were significantly younger (OR, 0.8; 95% CI, 0.76-0.94; $P = .002$) than patients in group 1.

Regardless of age and comorbidity profile, morphologic suitability remains the most relevant single criterion to select endovascular vs open surgical treatment, and the proximal extension of the disease is a major determinant for the endovascular suitability of the arch. Indeed, isolated aortic diseases confined to the arch are not frequent; the most common cause of endovascular exclusion being a large ascending aortic diameter, as shown by Sonesson et al[21] in a recent study analyzing anatomic feasibility of endovascular treatment for aortic arch aneurysms in Sweden based on measurements of the ascending and descending aorta and arch vessels. The authors found that only 7% (10 of 137) were possible candidates for endovascular repair.[21] In our study, we identified 42 mm as the largest aortic diameter feasible for the endovascular route because the largest commercially available stent graft size is 46 mm. Applying these criteria, 17% of our open arch candidates were feasible for endovascular repair. Our study confirmed the large ascending aorta diameter as the most relevant exclusion criterion from the endovascular approach to the arch. Of the 79 patients referred to one of our centers for repair of arch diseases (29 open and 50 endovascular), we found that two of three patients would have been suitable for endovascular repair with currently available techniques. Nevertheless, these feasibility rates should be interpreted with caution, because data were provided from a single center with a large endovascular experience and may not be largely generalizable.

The lack of data on long-term durability remains the most relevant limitation to the more extensive use of the less invasive approach to the arch. In this regard, our study failed to show any significant increased risk using an endovascular arch procedure, with freedom from late reintervention rates comparable to those in open surgery (94.6% in group 1 and 95.5% in group 2). Nevertheless, the unsuccessful reinterventions leading to two aortic-related deaths after persisting type I endoleak are reasons for concern: surveillance after any endovascular arch repair should be extremely accurate.

In disagreement with us, Sood et al[10] found that after propensity-adjusted Cox regression analysis, an endovascular procedure ($P = .001$) independently predicted late aortic rupture or need for reintervention 15 years after aortic arch repair. However, despite the long-term median follow-up of the study, data for direct comparison of freedom rates from aortic rupture and reinterventions in endovascular and open arch procedures were available only up to 2 years (78% vs 94%; $P = .02$).[10] It is expected that complications after open surgery for aortic arch repair require a longer time to develop, and only a few can be captured within this time frame. Furthermore, although we selected only zones 0 and 1, most hybrid arch repairs in the Sood et al[10] study required zone 2 landing, and this may have affected the difference in outcomes with our data.

Extending proximally the stent graft landing in the arch (zones 0 and 1) is known to be a determinant of increased stability of the repair,[3,9,22] whereas more distal landing (zones 2-4), where the curvature of the arch is more prominent, may render less stable the attachment of the stent graft to the arterial wall, thus predisposing to early and late adverse events. Nevertheless, the more proximal extension of the repair increases not only the long-term stability but also the operative risk in hybrid arch procedures.[8,9,19]

Some authors raised concern for hybrid treatment requiring proximal arch landing in the ascending aorta (zone 0) not only because of the higher perioperative mortality but also for the more frequent occurrence of retrograde type A dissection. Among 87 procedures with zone 0 or 1 coverage, Andersen et al[19] found 5.7% in-hospital mortality, that increased to 14.9% at 30 days. Retrograde type A dissection occurred in three zone 0 patients for an overall rate of 6.3% but a rate of 11.1% when including only patients with no previous ascending aorta replacement.[19]

Our 4.2% incidence of retrograde dissection, within the wide range of 1.3% to 6.8% shown in recent reports,[23,24] was recorded only after hybrid repair with total debranching (zone 0 landing) where the surgical manipulation of the ascending aorta might cause increased traumatic injury in the arterial wall, especially in patients with dissection.

However, extreme caution is required for any inference on causality of retrograde type A dissection due to the small number of such events in the present study.

Limitations of our study are related to the retrospective analysis not allowing a full assessment of confounders and minor outcomes and the sample size of the two groups given the rigorous selection. Nevertheless, we believe that the use of a concurrent open group for comparison at the opposite of an historical cohort ranging along several years in conjunction with the analysis of morphologic features allowed more strength in the present analysis.

An additional advantage was the detail of complications (including minor), reinterventions, and late outcomes. This allowed an inclusive view of the effect of current treatment for arch diseases, especially in frail older patients commonly referred to an endovascular approach. However, this issue needs to be better developed by further studies addressing quality of life in these patients.

Finally, these were heterogeneous groups in anatomy, physiology, and the pathology treated. To this regard, we did not use the propensity score to balance the different groups but simply to better identify the different criteria for treatment. At this time, with the available endovascular technology, forced balance with propensity score, or any proposal of random assignment of treatment to compare the outcome in patients with different risk exposure, seems less reasonable than clinical judgment and pragmatic reasoning in treatment choice.

CONCLUSIONS

In the present study, individualized treatment for aortic arch diseases with different endovascular or open procedures, performed in contemporary and concurrent series of patients, showed no significant differences in rates of perioperative death or stroke and freedom from reintervention at midterm, despite significant disparities in age and comorbidities, which were higher in the endovascular group.

With current endovascular technology, morphologic suitability for aortic arch diseases requiring zones 0 and 1 landing and age are the most important selection criteria to assign the appropriate approach for arch reconstruction.

Proper selection of alternative treatments based on best suitability criteria for open or endovascular approaches may be the best strategy to treat the arch today. Technological improvements may allow extending less invasive endovascular arch approachs also to less comorbid patient settings in the future.

AUTHOR CONTRIBUTIONS

Conception and design: PD, PC, CF
Analysis and interpretation: PD, PC, CF, FV, FM, CC, GP, AM
Data collection: PD, CF, FV, FM, CC, GP, AM
Writing the article: PD, PC, CF
Critical revision of the article: PD, PC
Final approval of the article: PD, PC, CF, FV, FM, CC, GP, AM
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REFERENCES

1. Ouzounian M, LeMaire SA, Coselli JS. Open aortic arch repair: state-of-the-art and future perspectives. Semin Thorac Cardiovasc Surg 2013;25:107-15.
2. Iba Y, Minatoya K, Matsuda H, Sasaki H, Tanaka H, Oda T, et al. How should aortic arch aneurysms be treated in the endovascular aortic repair era? A risk-adjusted comparison between open and hybrid arch repair using propensity score-matching analysis. Eur J Cardiothorac Surg 2014;46:32-9.
3. Kotelis D, Geisbüsch P, Attigah N, Hinz U, Hyhlik-Dürr A, Böckler D. Total vs hemi-aortic arch transposition for hybrid aortic arch repair. J Vasc Surg 2011;54:1182-6.
4. Cao P, De Rango P, Czerny M, Evangelista A, Fattori R, Nienaber C, et al. Systematic review of clinical outcomes in hybrid procedures for aortic arch dissections and other arch diseases. J Thorac Cardiovasc Surg 2012;144:1286-300.
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. Moulakakis KG, Mylonas SN, Dalainas I, Sfyroeras GS, Markatis F, Kotsis T, et al. The chimney-graft technique for preserving supra-aortic branches: a review. Ann Cardiothorac Surg 2013;2:339-46.
7. Hogendoorn W, Schlösser FJ, Moll FL, Sumpio BE, Muhs BE. Thoracic endovascular aortic repair with the chimney graft technique. J Vasc Surg 2013;58:502-11.
8. Vallejo N, Rodriguez-Lopez JA, Heidari P, Wheatley G, Caparrelli D, Ramaiah V, et al. Hybrid repair of thoracic aortic lesions for zone 0 and 1 in high-risk patients. J Vasc Surg 2012;55:318-25.
9. De Rango P, Cao P, Ferrer C, Simonte G, Coscarella C, Cieri E, et al. Aortic arch debranching and thoracic endovascular repair. J Vasc Surg 2014;59:107-14.
10. Sood V, Patel HJ, Williams DM, Dasika NL, Yang B, Deeb GM. Open and endovascular repair of the nontraumatic isolated aortic arch aneurysm. J Vasc Surg 2014;60:57-63.
11. Milewski RK, Szeto WY, Pochettino A, Moser GW, Moeller P, Bavaria JE. Have hybrid procedures replaced open aortic arch reconstruction in high-risk patients? A comparative study of elective open arch debranching with endovascular stent graft placement and conventional elective open total and distal aortic arch reconstruction. J Thorac Cardiovasc Surg 2010;140:590-7.
12. Murashita T, Matsuda H, Domae K, Iba Y, Tanaka H, Sasaki H, et al. Less invasive surgical treatment for aortic arch aneurysms in high-risk patients: a comparative study of hybrid thoracic endovascular aortic repair and conventional total arch replacement. J Thorac Cardiovasc Surg 2012;143:1007-13.
13. Murphy EH, Beck AW, Clagett GP, DiMaio JM, Jessen ME, Arko FR. Combined aortic debranching and thoracic endovascular aneurysm repair (TEVAR) effective but at a cost. Arch Surg 2009;144:222-7.
14. Lee CW, Beaver TM, Klodell CT Jr, Hess PJ Jr, Martin TD, Feezor RJ, et al. Arch debranching versus elephant trunk procedures for hybrid repair of thoracic aortic pathologies. Ann Thorac Surg 2011;91:465-71.
15. Benedetto U, Melina G, Angeloni E, Codispoti M, Sinatra R. Current results of open total arch replacement versus hybrid thoracic endovascular aortic repair for aortic arch aneurysm: a meta-analysis of comparative studies. J Thorac Cardiovasc Surg 2013;145:305-6.
16. Ishimaru S. Endografting of the aortic arch. J Endovasc Ther 2004;11(Suppl 2):II62-71.
17. Vallabhajosyula P, Szeto W, Desai N, Bavaria JE. Type I and type II hybrid aortic arch replacement: postoperative and mid-term outcome analysis. Ann Cardiothorac Surg 2013;2:280-7.

18. Bavaria J, Vallabhajosyula P, Moeller P, Szeto W, Desai N, Pochettino A. Hybrid approaches in the treatment of aortic arch aneurysms: postoperative and midterm outcomes. J Thorac Cardiovasc Surg 2013;145(3 Suppl):S85-90.
19. Andersen ND, Williams JB, Hanna JM, Shah AA, McCann RL, Hughes GC. Results with an algorithmic approach to hybrid repair of the aortic arch. J Vasc Surg 2013;57:655-67.
20. Zerwes S, Leissner G, Gosslau Y, Jakob R, Bruijnen HK, Oertl F, et al. Clinical outcomes in hybrid repair procedures for pathologies involving the aortic arch. Vascular 2014 Mar 12; [Epub ahead of print].
21. Sonesson B, Landenhed M, Dias N, Kristmundsson T, Ingemansson R, Koul B, et al. Anatomic feasibility of endovascular reconstruction in aortic arch aneurysms. Vascular 2014 Mar 12; [Epub ahead of print].
22. Gelpi G, Vanelli P, Mangini A, Danna P, Contino M, Antona C. Hybrid aortic arch repair procedure: reinforcement of the aorta for a safe and durable landing zone. Eur J Vasc Endovasc Surg 2010;40:709-14.
23. Khoynezhad A, White RA. Pathogenesis and management of retrograde type A aortic dissection after thoracic endovascular aortic repair. Ann Vasc Surg 2013;27:1201-6.
24. Yang J, Xiong J, Liu X, Jia X, Zhu Y, Guo W. Endovascular chimney technique of aortic arch pathologies: a systematic review. Ann Vasc Surg 2012;26:1014-21.

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