European Multicenter Registry for the Performance of the Chimney/Snorkel Technique in the Treatment of Aortic Arch Pathologic Conditions

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Background. **To study the performance of the chimney technique in the treatment of aortic arch pathologic conditions.**

Methods. **We retrospectively evaluated the clinical and procedural outcome data of patients undergoing endovascular treatment in the aortic arch by use of the chimney technique at four European centers between June 2002 and December 2014. The primary endpoint was technical success. The secondary endpoints were type I endoleak, 30-day mortality, stroke, primary patency of the chimney graft, and freedom from reintervention.**

Results. **Ninety-five patients were included in the study. The underlying pathologic conditions were degenerative aneurysm (n = 45, 47.4%), type B aortic dissection (n = 30, 31.6%), dissecting aneurysm (n = 6, 6.5%), penetrating atherosclerotic ulcer (n = 5, 5.3%), type I endoleak after previous thoracic endovascular aortic repair (n = 6, 6.3%), and aortic embolic disease (n = 3, 3.2%). Twenty-one patients (22%) underwent arch-branch debranching before chimney graft implantation. The majority of patients were treated electively (n = 49, 51.6%). Forty-six patients (48.4%) underwent urgent placement of chimney grafts because of their symptoms (n = 25) or rupture (n = 21). Technical success was 89.5%. The 30-day mortality was 9.5% (9 patients). No aorta-related death was observed. A type Ia endoleak occurred in 10 patients (10.5%) intraoperatively, resolving spontaneously within the first 30 days in 50% of these cases. Major stroke was diagnosed in 2 patients (2%). Primary patency of the chimney grafts was 98%, and 5 patients (5.2%) required a reintervention.**

Conclusions. **The chimney technique in the aortic arch proved highly and predictably successful, with a low rate of reinterventions.**

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Open surgical repair of lesions in the aortic arch and descending thoracic aorta is often accompanied by high mortality and morbidity [1, 2]. Endografting techniques have been introduced as less invasive treatment options. However, anatomic challenges abound because the lesions tend to be located in close proximity to or involving arch branches. For such cases, hybrid approaches are frequently undertaken to debranch the arch and to facilitate or enable endograft repair because landing zones can be thus created or lengthened.

The hybrid approaches have been reported to produce satisfactory outcomes with lower mortality and morbidity when compared with open surgical procedures [3, 4], but they imply the need for multiple procedures and ultimately may prove less appealing than a total endovascular approach using custom-made branched or fenestrated stent-grafts [5, 6]. The latter also carry significant demand on resources and costs, and the need for customization rules out their use in urgent or emergent settings.

The chimney technique [7] emerged as a component of a total endovascular solution for the management of difficult aortic pathologic conditions in urgent and acute settings, and with the ability to use off-the-shelf devices. The literature provides only scant information on the performance of chimney and parallel grafts in the aortic arch, with published reports describing analyses of small patient series comprising usually no more than 10 to 15 treated patients each [8–15]. We have set out to remedy this situation by providing the outcome information on nearly 100 cases collected in the European Registry herein reported, with analysis performed by use of a standardized evaluation protocol.

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Material and Methods

Patients

Four European centers provided data on all patients undergoing endovascular treatment of aortic arch pathologic conditions with the chimney technique between June 2002 and December 2014. The four centers included Barcelona, Muenster, Rome, and Zurich. All patients were high-risk candidates for open surgical procedures because of severe cardiac disorders, respiratory disorders, or both, and they gave written informed consent. The registry was conducted based on the principles of the Declaration of Helsinki. The local ethics committee and Institutional Review Boards approved the data collection and analysis.

The treated aortic arch pathologic conditions included degenerative aneurysms larger than 55 mm in diameter, type B aortic dissections (TBAD), penetrating aortic ulcers (PAU), aortic embolic disease, and patients with type I endoleak after previous thoracic endovascular aortic repair (TEVAR).

Device and Repair

The selection of chimney graft type and aortic stent-graft was based on each institutional practice and the surgeon's preference, as were other technical aspects of the TEVAR procedures performed. There were no device exclusions.

Data Collection and Analysis

Patient demographics, risk factors, whether treatment was elective or urgent, type of pathologic condition, type of endograft, and graft selections, and key anatomic features such as aneurysm diameter and neck length were all collected and recorded for each patient. Preoperative and postoperative computed tomographic scans were reviewed by the use of three-dimensional workstations, and measurements were made with a center line–based method. Aneurysm neck length, or the length of the proximal landing zone, was defined as the distance between the distalmost margin of the origin of the left subclavian artery (LSA) and the beginning of the aortic lesion. Postoperatively, the definition of such length was changed to the distance between the beginning of the covered part of the endograft and the beginning of the aortic lesion. Ishimaru's aortic arch zones were used to denote the proximal landing of the endograft. Each center performed this analysis separately using workstations.

Endpoints and Outcome Measures

The primary endpoint was technical success. The secondary endpoints were type I endoleak, 30-day mortality, stroke, primary patency of the chimney grafts, and freedom from reintervention.

Technical success was defined as successful endograft deployment with exclusion of the lesion, patency of the target branch vessel with the chimney graft, and no type I endoleak.

Statistical Analysis

The statistical analysis was performed with SPSS software (version 22.0; IBM Corporation, Armonk, NY). The data are presented as mean ± standard deviation and range. The categoric data are provided as the count and percentage. The differences between two groups were analyzed with the Mann-Whitney *U* test. Kaplan-Meier methods were used to estimate overall survival, primary patency, and reintervention rate for the chimney graft. Statistical significance was reached when $p < 0.05$.

Results

Ninety-five patients (61 men; mean age 68 years; range, 23 to 87 years) with aortic arch pathologic conditions were treated by the chimney technique and included in the registry. The patient demographics and baseline clinical data are presented in Table 1. The device characteristics and chimney grafts used are shown in Table 2.

The Gore TAG endograft (W.L. Gore & Assoc, Flagstaff, AZ) was most frequently used (57 patients, 60%). The total number of chimney stents used was 102. These were balloon-expandable covered stents (BECS) (n = 29, 28.4%), self-expandable covered stents (SECS) (n = 61, 59.8%), and bare-metal stents (n = 12, 11.8%). The LSA was the target vessel in 61.8% of cases (n = 63), the left common carotid artery (LCCA) in 23.5% (n = 24), the brachiocephalic trunk (BCT) in 12.7% (n = 13), and an

Table 1. Patient Demographics and Baseline Characteristics

Age, y, mean ± SD (range)	67.8 ± 13 (23–87.3)
ASA class, n (%)	
I	1 (1)
II	16 (16.8)
III	47 (49.6)
IV	23 (24.2)
V	8 (8.4)
Hypertension	83 (87.4)
Coronary artery disease	30 (31.6)
Chronic heart failure	7 (7.4)
Diabetes mellitus	16 (16.8)
Hypercholesterolemia	27 (28.4)
COPD	39 (41.4)
Renal insufficiency	20 (21.1)
Tobacco use	44 (46.3)
PAD	8 (8.4)
Disease, n (%)	
Aneurysm	45 (47.2)
Type B dissection	30 (31.6)
Dissecting aneurysm	6 (6.3)
PAU	5 (5.3)
Morbus embolicus	3 (3.2)
Type I endoleak	6 (6.3)
Clinical status, n (%)	
Asymptomatic	49 (51.6)
Symptomatic or ruptured	46 (48.4)

ASA = American Society of Anesthesiologists; COPD = chronic obstructive pulmonary disease; PAD = peripheral artery disease; PAU = penetrating arteriosclerotic ulcer; SD = standard deviation.

Table 2. Device Type and Chimney Characteristics

Device, n (%)	
Gore TAG	57 (60)
Zenith TX	19 (20)
Valiant	8 (8.4)
Bolton	5 (5.3)
Zenith	3 (3.2)
Talent	2 (2.1)
Unknown	1 (1.1)
Chimney graft, n (%)	
Balloon expandable covered	29 (28.4)
Self expandable covered	61 (59.8)
Bare metal	12 (11.8)

aberrant right subclavian artery (aRSA) in 2% (n = 2). The Gore TAG endograft was mainly used in association with SECS (96.5%) such as the Viabahn (W.L. Gore & Assoc); a bare-metal stent was used in other cases. The Valiant endograft (Medtronic Vascular, Santa Rosa, CA) was combined with the BECS such as the Advanta stent-graft (Atrium Medical, Hudson, NH) in 75%. The Zenith endograft (Cook Medical, Bloomington, IN) was combined with BECS in 77% of such instances.

The underlying aortic arch pathologic conduitions included degenerative aneurysm (n = 45, 47.2%), TBAD (n = 30, 31.6%), dissecting aneurysm (n = 6, 6.5%), PAU (n = 5, 5.3%), aortic embolic disease (n = 3, 3.2%), and type I endoleak after previous TEVAR (n = 6, 6.3%).

Twenty-one patients (22%) underwent debranching before chimney graft implantation.

Elective Versus Emergent Chimney Graft Placement and Cervical Bypasses

Forty-nine patients were treated electively (51.6%) and 46 (48.4%) urgently because of symptoms or rupture. Nine patients (9.6%) underwent both chimney graft implantation and debranching, and in only 1 of these patients was more than 1 chimney graft implanted. In 11 patients (11.6%), two or more branch vessels were revascularized with chimney grafts. Seven of these (63.6%) were symptomatic or had a rupture, and only 1 patient needed an additional debranching bypass (a right common carotid-to–left common carotid bypass to left subclavian artery bypass: RCCA-LCCA-LSA). Overall, 21 patients (22%) underwent arch debranching, and 9 (43%) of these were symptomatic or had a rupture. Six patients underwent an LSA transposition, 8 underwent an LCCA-LSA bypass, and in 7 an RCCA-LCCA-LSA bypass was performed. The debranching was performed concomitantly with TEVAR (during the same procedure) in 44% of the patients. In 56% of the patients the aortic arch pathologic condition involved the entire arch: TBAD in 33% and aneurysm in 67%.

Outcomes

Technical success was 89.5%. A type Ia endoleak was detected on completion angiography in 10 patients (10.5%) despite postballooning by use of the kissing technique. All chimney grafts were placed as intended and were seen to be patent in the final angiogram. Neck length was zero (0 mm) in 30 patients. The other 65 patients had a mean neck length of 6.9 mm ± 4.9 mm (range, 1 to 19 mm). After the procedure, the mean neck length was 26.5 mm ± 7.4 mm (range, 10 to 57 mm) ($p < 0.001$).

The 30-day mortality was 9.5% (9 patients). The causes of death were heart failure, cardiac arrest, or both (n = 3), major stroke (n = 2), a retrograde type A dissection (n = 1), multiorgan failure (n = 1), hemorrhagic shock after open conversion for a type I endoleak (n = 1), and unknown (n = 1). Forty-four percent were at American Society of Anesthesiologists class 4 or higher at the time of operation.

Four patients had a stroke within 30 days (4.2%). Two patients died of major stroke, and 2 patients experienced a minor stroke that resolved spontaneously and completely after a few weeks. One of the 2 patients who died had three chimneys placed (SECS) to preserve all arch branches. The other was treated for a symptomatic aneurysm with a chimney for the LCCA (SECS) and overstenting of the LSA. The overall survival during a mean follow-up time of 24 months (range, 1 to 144 months) is shown in Figure 1. No late aorta-related deaths occured.

Endoleaks

Ten patients (10.5%) had an intraoperative type Ia endoleak on completion angiography. The patient profiles, device types, and treatment are shown in Table 3. Four patients had a type Ib endoleak (4.2%), and 16 patients had a type 2 endoleak (16.8%). In all such instances, type Ib endoleaks were related to elective first-stage repair of asymptomatic thoracoabdominal aortic aneurysm to minimize the risk of paraplegia.

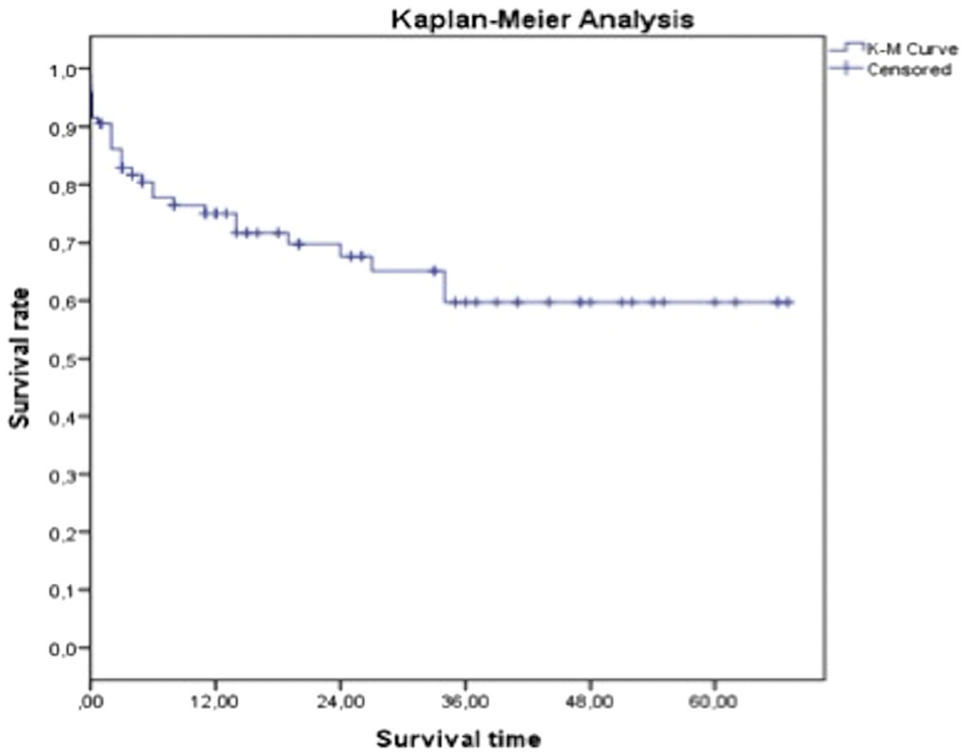
Five (50%) of the 10 type Ia endoleaks resolved spontaneously within the first 30 days postoperatively. One patient was treated with coil embolization after 3 months and showed no further type Ia endoleak during follow-up. Other treatment options for type Ia endoleaks included RCCA-LCCA-LSA bypass (n = 1), open conversion (n = 1), proximal extension with cuff implantation (n = 1), and observation and no reintervention in a case of low-flow type Ia endoleak and transient paraparesis (n = 1). Two of the patients with type Ia endoleak died of multiorgan failure and heart failure.

Primary Patency and Freedom From Reintervention

Primary patency for the chimney grafts was 98 % (Fig 2). Two were found occluded after 9 days and 30 days, respectively. Both patients with occluded SECS chimney grafts in the LSA were asymptomatic (and were receiving coumadin at the time of occlusion). Both occluded chimney grafts underwent successful endovascular thrombectomy and recanalization; an underlying cause was not found.

The freedom from reintervention rate was 96.5 % at 12 months, 93.6% after 2 years, and 88.6% after 5 years (Fig 3). Overall, 2 of 5 patients requiring chimney-related reintervention had occlusion of the chimney graft, another 2 patients had high-grade in-stent stenosis, and

Fig 1. Overall survival.



1 patient had an LSA BECS chimney-related endoleak. That last patient was treated 2 months later with placement of a SECS device.

One patient underwent placement of a bare-metal stent into an SECS in the LCCA for treatment of chimney stenosis at 21 months, and a BECS device in the LSA after 36 months. Figure 4 shows the case of a ruptured thoracic aneurysm very close to the LSA with an aRSA coming off the aneurysm. The aRSA was overstented and the LSA preserved by use of the chimney technique. No endoleak was observed on the completion angiogram or during the 2-year follow-up.

Comment

This report represents the largest patient series in the literature with aortic arch pathologic conditions treated with the chimney technique. The midterm results show a

Table 3. Type I Endoleaks

Disease	Type of Endograft	Type of Chimney Graft	Location of Chimney	Treatment
Dissecting aneurysm, asymptomatic	Gore TAG	SECS	LSA + LCCA	Spontaneous resolution
Type B dissection, symptomatic	Gore TAG	SECS + bypass RCCA-LCCA-LSA	BT	Coiling after 3 months
Aneurysm, asymptomatic	Gore TAG	SECS	LSA	Bypass RCCA-LCCA-LSA + overstenting because of distal migration
Dissecting aneurysm, symptomatic	Gore TAG	SECS	LCCA	Spontaneous resolution
Aneurysm, asymptomatic	Gore TAG	SECS	LCCA	Spontaneous resolution
Aneurysm, asymptomatic	Gore TAG	SECS	LCCA	Spontaneous resolution
Type B dissection, symptomatic	Bolton	BECS	LCCA	Conversion
Aneurysm, ruptured	Zenith TX	BECS	LSA	No treatment because of paraparesis
Aneurysm, symptomatic	Zenith TX	SECS	LSA	Proximal expansion + chimney BT because of poor adaptation outer wall
PAU, symptomatic	Zenith TX	BECS + SECS	LSA (aneurysmatic)	Spontaneous resolution

BECS = balloon-expandable covered stent; BT = brachiocephalic trunk; LCCA = left common carotid artery; LSA = left subclavian artery; PAU = penetrating arteriosclerotic ulcer; RCCA = right common carotid artery; SECS = self-expandable covered stent.

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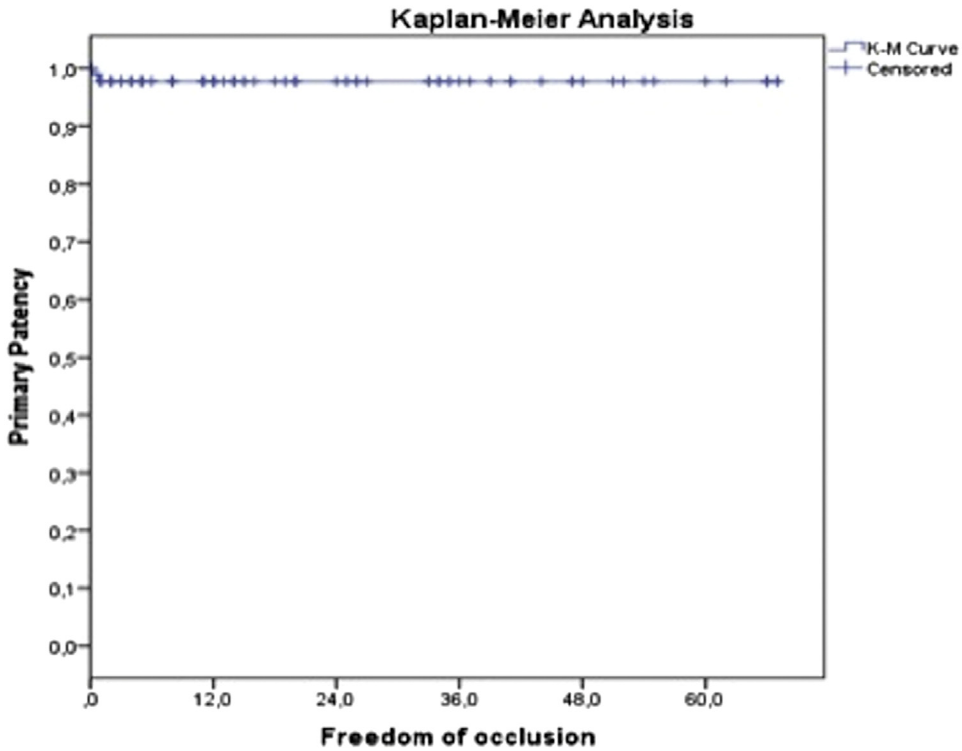

Fig 2. Primary patency of the chimney graft.

high rate of technical success and only few reinterventions, highlighting the utility of the technique, especially for urgent indications. Figure 4 is a good example of such capabilities.

The significant increase in neck length afforded by chimney graft placement enabled successful endograft fixation and seal, without type Ia endoleak. In this context, combinations of a suitably sized thoracic aortic stent-graft

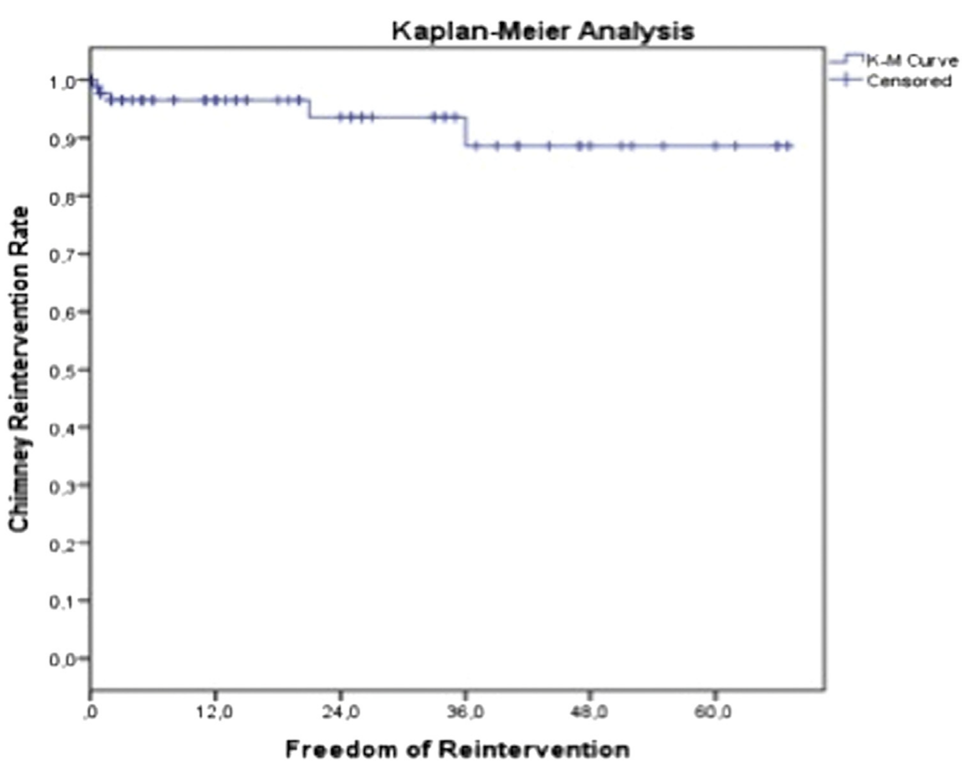

Fig 3. Freedom from reintervention of the chimney graft.

Fig 4. (A) Rupture site of the aneurysm and the lusorion artery. (B) Intraoperative angiographic view showing the endograft in place and a sheath coming from the left subclavian artery. (C) Intraoperative angiographic view showing deployment of the endograft and chimney stent-graft. (D) Postoperative contrast-enhanced computed tomographic scan.

with arch-branch chimney(s) using SECS and BECS seem to work quite well, with good conformability of the devices as they interact with each to minimize the formation of gutters.

Hogendoorn and colleagues [10] recently published a metaanalysis of previously reported studies involving the chimney technique in the aortic arch. Unfortunately, their analysis was compromised and their conclusions limited by an incomplete dataset in terms of technical information, and it lacked key procedural details such as the type of chimney graft in 13% of the patients and poor follow-up information. To overcome these limitations, we collected the current European experience having completed imaging follow-up for all patients and precise characterization of all used devices. The satisfactory results we encountered seem to support wider applicability of the chimney technique, particularly in urgent cases where the utility of such strategy is undeniable.

Other techniques with the use of custom-made fenestrated and branched endografts have been described [11, 16, 17]. A disadvantage of such techniques is the required waiting period and greater technical expertise and costs. O'Callaghan and colleagues [11] have reflected on this, suggesting that fenestrated grafts offer only limited utility and many potential disadvantages. Haulon and colleagues [17] have reported the use of an inner-branch endograft for the aortic arch, without much advantage in terms of stroke risk in comparison with the chimney technique. But on the upside, they have shown enhanced sealing and aneurysm exclusion and very few type I endoleaks [16].

Gutter-related type I endoleaks and risk of embolic stroke related to upper extremity arterial access remain major issues. The observed patient outcomes in this registry demonstrated that 50% of the type Ia endoleaks resolved spontaneously within the first 30 days and that only 5.4% of all patients underwent a secondary procedure for treatment of a persistent type I endoleak. Four of these 5 patients were symptomatic. This (along with common sense) suggests that type I endoleaks seen on final angiography and persisting beyond the first postoperative month must be treated if possible. Proximal extension of the repair, gutter, or both, and endoleak embolization might be needed. Hogendoorn and colleagues [10] reported similar findings in their review article, with a type I endoleak rate of 6.4%.

The concept of having or creating a minimum neck length of 20 mm is important if type I endoleak is to be avoided. Previous publications tend to substantiate this dictum [8, 13, 18]. The underlying thought is that gutters are minimized and adaptation of the endograft around the chimney stent is enhanced with longer lengths of overlap between the two devices inside the aorta. Other factors must also be taken into account, especially those related to the anatomic and geometric configuration of the arch, avoiding bird-beaking along the lesser curve at the apex and the possible presence of prominent atherosclerotic disease and plaques within the arch [19, 20].

Whether or not to cover the LSA origin has been discussed and studied at length during the past decade. Most publications and opinions point to an increased risk of stroke with LSA coverage and more proximal landing of the thoracic endograft [21–23]. In this registry, the stroke rate was 4.2%, which is no higher than the expected rate after performance of a debranching carotid-subclavian bypass [24]. Higher rates have been reported [25, 26].

Noteworthy are some limitations of this study because of its retrospective nature and the absence of a centralized core laboratory to evaluate imaging-based findings. However, the data collection was performed according to a standardized protocol, and no industry funding was sought or received.

Conclusion

The use of the chimney technique to facilitate and enhance the endovascular treatment of aortic arch pathologic conditions is feasible and safe. Off-the-shelf availability and suitability to treat a wide variety of lesions in elective and urgent settings remain the major strengths of the chimney strategy. As observed, the combinations of the Gore TAG and Medtronic Valiant thoracic devices with the SECS and BECS, respectively, is associated with a low rate of gutter-related type I endoleak. Long-term follow-up is required to evaluate the occurrence of late type I endoleak and ultimately the durability of this technique.

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