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REVIEW

Sealing Devices in Chimney Aortic Repair (CH EVAS) Versus Chimney Aortic Repair with Conventional Devices (CH EVAR): A Systematic Review

Daniela Mazzaccaro[1] · Alberto M. Settembrini[1] · Lorenzo Muzzarelli[1] · Federico Ambrogi[2] · Valentina Milani[3] · Giovanni Nano[1,4]

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Abstract
Aim The aim of this study was to review the literature about the occurrence of postoperative type I endoleak (EL) and chimney graft thrombosis (CGT) after the use of sealing devices in chimney endovascular aortic repair (Ch EVAS), compared to chimney EVAR using conventional devices (Ch EVAR).
Methods A systematic review of the literature on PubMed and MEDLINE with the terms "Chimney" and "Parallel grafts" was performed. The review was set up following the PRISMA guidelines. Case series about the use of the chimney/snorkel technique during endovascular repair of juxtarenal/pararenal aneurysms (AAA) were considered. Only papers with full text available in English and reporting complete data with at least 1 month of follow-up about at least 5 cases were included in the analysis.
Results In total, 90 papers were assessed for eligibility. According to the inclusion criteria, only 25 papers could be analyzed (20 in the Ch EVAR group and 5 in the Ch EVAS group). A type I EL occurred in 9.3% after Ch EVAR (95% CI 7.1–12.2%) and in 8.3% after Ch EVAS (95% CI 3.5–18.5%), being not significantly different. CGT occurred in 10.7% of cases after Ch EVAR (95% CI 8.8–13%) and in 8.8% of cases after Ch EVAS (95% CI 3.3–21.3%), being also not significantly different.
Conclusions The reported rate of type I EL and CGT occurring after Ch EVAR tended to be slightly higher than those reported after Ch EVAS, even if the difference was not statistically significant.

Keywords Chimney graft/technique · EVAR · EVAS · Abdominal aortic aneurysm · Aneurysm sealing

Introduction

The "chimney technique" has been proposed since few years as an "off-the-shelf" solution for the endovascular aortic repair (EVAR) of complex abdominal aneurysms either with a lack of adequate proximal aortic neck or involving the ostium of renal/splanchnic vessels [1]. Concerns, however, have been raised in the last years about the gutters formation, which frequently occur for the loss of continuous apposition between the main body of the endograft, the parallel stent grafts and the native aortic wall [2], and uncertainties remain about their natural history given the risk of postoperative type I endoleak (EL).

Further concerns with chimney EVAR regard the risk of chimney graft compression due to radial force, which can induce stent thrombosis. Depending on the affected artery, chimney graft thrombosis (CGT) may occur without any

✉ Daniela Mazzaccaro
danymazzak83@libero.it; daniela.mazzaccaro@gmail.com; daniela.mazzaccaro@grupposandonato.it

[1] First Unit of Vascular Surgery, IRCCS Policlinico San Donato, Piazza Malan, 1, 20097 San Donato Milanese, MI, Italy

[2] Department of Clinical Sciences and Community Health, University of Milan, Milan, Italy

[3] Scientific Directorate, IRCCS Policlinico San Donato, San Donato Milanese, Italy

[4] Department of Biomedical Sciences for Health, University of Milan, Milan, Italy

symptoms, but it can also lead to acute renal failure, especially when the chimney stents are placed in both renal arteries [3].

The concept of an "endovascular sealing system" (EVAS), referred to the presence of a sealing polymer around the endograft, has been introduced since 2013 with the aim of reducing the incidences of EL and consequent reinterventions observed after conventional EVAR [4] and has been gradually employed in combination with parallel grafts. The sealing polymer in fact may act with a dual mechanism: First, it can fill the gutters, preventing the occurrence of type I EL. In addition, it may conform more precisely around the chimney stent grafts without any competition with the radial strength of the chimney grafts, reducing the risk of graft compression [5], especially when self-expandable chimney grafts are used [6].

The literature, however, lacks clinical studies that compare the postoperative results of Ch EVAS versus Ch EVAR.

Therefore, we aimed to perform a systematic review of the literature, in order to compare the occurrence of postoperative type I EL and CGT after the use of sealing devices in Ch EVAS versus chimney EVAR using conventional devices (Ch EVAR).

Materials and Methods

Details of the protocol for this systematic review were registered on PROSPERO and can be accessed at www.crd.york.ac.uk/PROSPERO/display_record.asp?ID=CRD42018090689.

Institutional review board approval was not needed for this research.

Analysis of the literature on PubMed and MEDLINE with the terms "Chimney" and "Parallel grafts" was performed. The review was set up following the PRISMA guidelines [7]. Case series about the use of the chimney/snorkel technique during endovascular repair of juxtarenal/pararenal aneurysms (AAA) were considered. Only papers with full text available in English and reporting complete data with at least 1 month of follow-up about at least 5 cases were included in the analysis.

Reviews and technical notes without case series and case reports about Ch EVAR for occlusive aorto-iliac disease were excluded, as well as papers in which Ch EVAR was performed using adjunctive endoanchors to improve the proximal sealing of the endograft. Papers reporting data partially or completely included in other case series were also excluded.

Two independent investigators performed the search of the literature and reviewed each paper that was considered appropriate according to the inclusion criteria. The results of each investigator were then compared to see whether they were in concordance. If a paper had been included by an investigator but not by the other, a third independent investigator decided for the inclusion of the paper and analyzed the results.

Given the lack of comparative studies in the literature between Ch EVAR and Ch EVAS, the projected difference between the two sets of observation could not be calculated.

For both Ch EVAR and Ch EVAS, the total proportion of type I EL and TVT occurring during the follow-up was calculated using both fixed and random effect models, along with the respective 95% confidence intervals (CIs). Median and inter-quartile range (IQR) were used to indicate the follow-up. The R program (http://CRAR.R-project.org) with "Metaprop" package, a statistical online software for metaanalysis, was used to compare each pair of proportions. The DerSimonian–Laird estimator was used to quantify the heterogeneity (τ^2) among the different studies for both Ch EVAR and Ch EVAS, with each respective P value. Chi-square test was also performed to compare the raw data of type I EL and TVT between the two groups. A P value < 0.05 was considered statistically significant.

Results

The search on the literature retrieved a total of 5380 items on PubMed and 2831 items on MEDLINE. After deleting the papers that were duplicated in the two databases, 5835 papers were assessed. Of them, 5745 were excluded. In fact, following the abstract, 167 of them reported about chimney either in thoracic EVAR or in the aortic arch and 154 were literature reviews or technical notes without any case series. Sixty-one papers reported about either EVAR or EVAS without chimney. The remaining papers could not be analyzed because either they were not written in English or the pdf of the full-length article was not available. A total of 90 papers were then assessed. According to the inclusion criteria, only 25 papers could be analyzed (20 in the Ch EVAR group and 5 in the Ch EVAS group, Fig. 1).

Both investigators were in concordance about which paper needed to be included and which one did not meet the inclusion criteria in all except one paper, which finally was excluded from the analysis by the third investigator.

Data about 952 Ch EVAR and 79 Ch EVAS performed from January 2008 to August 2017 were then analyzed (Table 1).

In all except two papers [19, 31], the authors specified which target visceral vessels were intervened upon. Among those papers, a total of 1634 chimney vessels were deployed, being in most cases one or both renal arteries

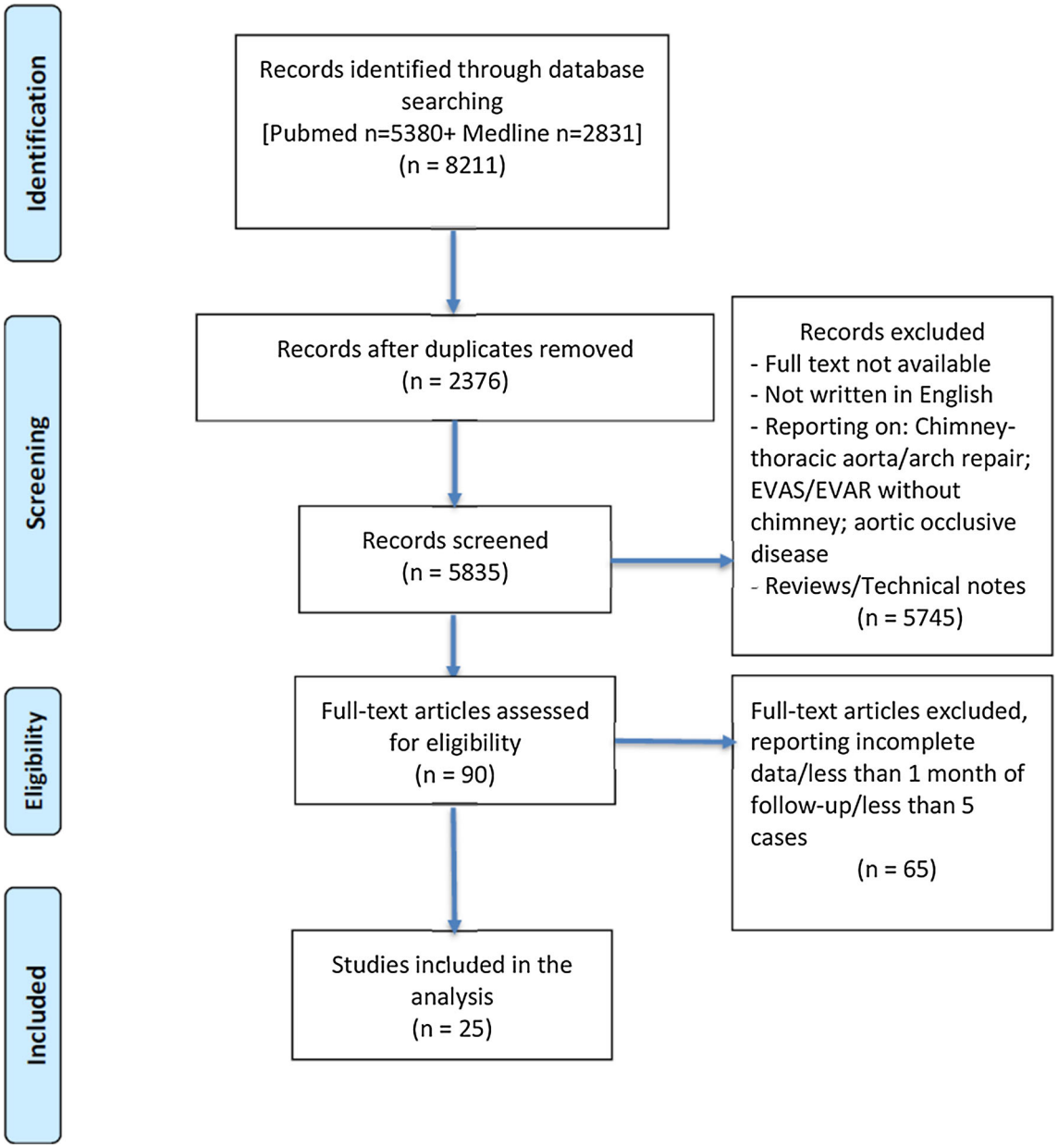

Fig. 1 Flowchart of the papers retrieved from the literature search and included in the analysis, according to the PRISMA guidelines

(n = 1303), followed by the superior mesenteric artery (n = 251).

As for the type of stent used for the chimney, covered stents were preferred over bare metal stents, which were used especially to give additional support to the chimney graft. Balloon-expandable stents and self-expanding stents were used.

Among the considered papers, Donas et al. [14] in the PERICLES study reported the largest series of Ch EVAR, with a 97.1% of technical success on 517 patients. The authors reported the occurrence of 5 type I EL and 54 stent thrombosis during a mean follow-up of 17.1 ± 8.2 months. Similarly, De Bruin et al. [8] described the results of the largest series of Ch EVAS with a 100% of technical success rate on 28 patients. They reported 3 cases of type I EL and 1 chimney graft stenosis, however, with a shorter follow-up (median 123 days).

Most EL and CGT required a reintervention, both after Ch EVAR and after Ch EVAS (Table 1). In particular, when the thrombosis occurred in the renal arteries, it was more likely to induce renal failure, so surgical treatment was mandatory in most cases.

The heterogeneity of the reported study was not statistically significant. According to the "Metaprop" analysis (Table 2), during a median follow-up of 14.8 months (IQR 7.5–23.7 months), a type I EL occurred in 9.3% after Ch

Table 1 Details of the 25 case series which were included in the analysis

Author, year of publication	Ch EVAR/ Ch EVAS	Nr. of pts	Technical success (%)	Type of target vessels	Type of stent used for chimney	Type I EL during follow-up	CGT during follow-up
Youssef, 2016 [5]	Ch EVAS	10	100	17 RA 4 SMA 2 CT	23 BECS	0 @ 8 months	0 @ 8 months
De Bruin, 2016 [8]	Ch EVAS	28	100	39 RA 8 SMA	BECS/SECS[#]	3 (1 requiring onyx and coils embolization @ 10 months)	0 @ 4 months (1 stenosis treated with angioplasty @ 7th POD)
Dinkelman, 2016 [9]	Ch EVAS	16	100	25 RA 1 SMA	26 BECS	1 @ 1 month	2 @ 1 month (both RA in the same patient) → dialysis
Igari, 2016 [10]	Ch EVAR	12	91.6	15 RA	15 BEUS	1 @ 2 years requiring coils embolization	2 (within 6 months postop) → asymptomatic
Abu Bakr, 2016 [11]	Ch EVAR	9	100	9 accessory RA	BECS/SECS[#]	0 @ 13.8 months	1 @ 30 days → renal function impairment after 12 months
Silveira, 2016 [12]	Ch EVAR	35	100	45 RA 6 SMA	36 BECS, 9 BEUS, 1 SECS	2 (1 @ 30 days, 1@ 36 months requiring iliac limb extension	1 @ 36 months (+ 2 stenosis > 75% requiring angioplasty and bare metal stenting relining)
Bin Jabr, 2016 [13]	Ch EVAR	51	82	55 RA 17 SMA 1 CT	18 SE, 41 BE, 14 combined (coverage n.a.)	6 (3 immediately, 1 of them requiring Palmaz restenting; 1 @5 days requiring stent extension; 1 @ 15 days requiring onyx embolization; 1 @14 months requiring onyx embolization)	7 (2 SMA @ 1 and 7 days requiring restenting; 4 RA and 1 SMA @ 24.7 months), + 2 RA stenosis @15 and 30 months requiring restenting
Donas, 2015 [14]	Ch EVAR	517	97.1	692 RA 156 SMA 50 CT	442 BECS, 355 SECS, 101 BMS	5 (2 requiring open conversion; 3 @30 months requiring additional chimneys)	54 @ 17.1 months
Montelione, 2015 [15]	Ch EVAR	24	96	44 RA 8 SMA 3 CT	76 SECS, 19 BMS	4 (1 @ 18 months requiring aortic banding, 2 @ 5 and 28 months requiring onyx embolization, 1 @ 29 months requiring redo Ch EVAR)	1 RA occlusion @1 month requiring SMA-RA bypass (+ 1 SMA occlusion @ 10 months requiring angioplasty)
Xiaohui, 2015 [16]	Ch EVAR	42	100	56 RA	70 BEUS	8 @ completion angiography (3 resolved by 6 months, 5 managed conservatively)	1 RA @ 3 months → asymptomatic
Scali, 2014 [17]	Ch EVAR	40	92.5	51 RA 16 SMA 9 CT	26 BECS, 11 SECS, 7 SEUS	3 (1 @ 14.2 months requiring open conversion, 1 @ 34.4 pending revision, 1 n.a.)	9 (1 CT @ 22 months requiring celiac bypass; 1 SMA @ 7.5 months asymptomatic; 1 SMA n.a.; 1 bilateral RA @ 40.4 months requiring dialysis and renal bypass; 1 bilateral RA @ 10.8 months requiring dialysis; 2 RA @ 0.5 and 11.5 months asymptomatic)

Table 1 continued

Author, year of publication	Ch EVAR/ Ch EVAS	Nr. of pts	Technical success (%)	Type of target vessels	Type of stent used for chimney	Type I EL during follow-up	CGT during follow-up
Tran, 2016 [18]	Ch EVAR	52	98.1	85 RA	BECS, SECS, SEUS#	4 @ discharge (3 resolved by 6 months, 1 requiring reintervention @ 6 months)	4 @ 1, 2, 3, 6 months
Schwerz, 2014 [19]	Ch EVAR	32	87.5	n.a.	SECS, BECS, BMS#	5#	6#
Ducasse, 2013 [20]	Ch EVAR	22	95.4	22 RA	22 SEUS	0 @ 18 months	0 @ 18 months
Banno, 2014 [21]	Ch EVAR	38	94.7	50 RA 10 SMA	32 BECS; SECS, SEUS#	2 @ 12 months	1 SMA @ 23 days requiring ilio-mesenteric bypass and colectomy
Fukui, 2013 [22]	Ch EVAR	10	100	10 RA	10 BEUS	0 @ 9.8 months	0 @ 9.8 months
Suominen, 2013 [23]	Ch EVAR	7	85.7	11 RA	11 BECS	0 @ 22 months	0 @ 22 months
Liu, 2013 [24]	Ch EVAR	5	100	6 RA	5 BE, 1 SE (coverage n.a.)	0 @ 15.8 months	0 @ 15.8 months
Schiro, 2013 [25]	Ch EVAR	9	88.9	9 RA	9 BECS	2 @ discharge which resolved @ 12 months	0 @ 12 months
Pecoraro, 2011 [26]	Ch EVAR	9	88.9	11 RA 6 SMA 7 CT	BECS/SECS/BMS#	6 by few days (3 of them requiring treatment) + 1 @ 10 months treated conservatively	0 @ 10 months
Bruen, 2011 [27]	Ch EVAR	21	95.2	28 RA 9 SMA	29 BECS 10 SEUS 3 BEUS 2 SECS	1 @ 30 days (which resolved by 6 months)	1 SMA @ 6 months → asymptomatic (+ 1 SMA partial compression @ 6 months requiring balloon angioplasty)
Ohrlander, 2008 [28]	Ch EVAR	6	100	9 RA 2 SMA	6 BECS, 4 BEUS	0 @8 months	0 @ 8 months
Ronchey, 2015 [29]	Ch EVAR	20	100	27 RA 1 SMA 1 CT	27 SECS, 2 BMS	0 @ 30.9 months	1 @ 11 months → asymptomatic
Youssef, 2016 [30]	Ch EVAS	7	100	14 RA 7 SMA 7 CT	28 BECS	0 @ 6 months	1 @ 6 months → asymptomatic
Harrison, 2018 [31]	Ch EVAS	18	100	n.a.	n.a.	1 (follow-up n.a.)	0 (follow-up n.a.)

pts patients, *EL* endoleak, *CGT* chimney graft thrombosis, *RA* renal artery, *SMA* superior mesenteric artery, *CT* celiac trunk, *BECS* balloon-expandable covered stents, *SECS* self-expanding covered stents, *BEUS* balloon-expandable uncovered stents, *SEUS* self-expanding uncovered stents, *BMS* bare metal stents, # not specified, *n.a.* not available

Table 2 Total proportion of type I EL and target vessels thrombosis occurring after Ch EVAR and Ch EVAS, calculated using both fixed and random effect models, along with the respective 95% confidence intervals (CIs). Heterogeneity (τ^2) among the different studies for both Ch EVAR and Ch EVAS, along with each respective *P* value, was also reported

	Ch EVAR	Ch EVAS	τ^2	*P* value
Type I endoleak				
Proportion (95% CI), fixed effect model	0.093 (0.071–0.122)	0.083 (0.035–0.185)	0.04	0.16
Proportion (95% CI), random effect model	0.090 (0.051–0.151)	0.083 (0.035–0.185)	0	0.91
Target vessels thrombosis				
Proportion (95% CI), fixed effect model	0.107 (0.088–0.130)	0.088 (0.033–0.213)	0.04	0.36
Proportion (95% CI), random effect model	0.107 (0.085–0.134)	0.088 (0.033–0.213)	0	0.77

EL endoleak, *CI* confidence interval

EVAR (95% CI 7.1–12.2%) and in 8.3% after Ch EVAS (95% CI 3.5–18.5%), being not significantly different. CGT occurred in 10.7% of cases after Ch EVAR (95% CI 8.8–13%) and in 8.8% of cases after Ch EVAS (95% CI 3.3–21.3%), being also not significantly different.

Discussion

The "chimney technique" has been introduced since few years as an "off-the-shelf" solution for the endovascular repair of complex juxtarenal and suprarenal abdominal aneurysms, which cannot be treated using either conventional open repair or branched/fenestrated endografts [1].

The use of chimney grafts, in fact, allows to extend the proximal landing zone in order to achieve a proper sealing for successful exclusion of the aneurysm with standard endograft devices, even in an emergent setting [32], where branched and fenestrated "custom-made" grafts are not available.

Current evidence about Ch EVAR shows promising clinical results [1]. The initial enthusiasm about this technique, however, has been slightly cooled down by the report of some complications, on the opposite side [2]. Type I EL represents one of the most criticized issues of this technique. In fact, "gutters" frequently occur for the loss of continuous apposition between the main body of the endograft, the parallel stent grafts and the native aortic wall [2]. According to some authors, those gutters do not always involve the formation of a type I EL, or sometimes gutter-related type Ia EL after Ch EVAR may have a benign natural history [33]. Donas and Coll [14] in the PERICLES study reported the occurrence of only 5 type I EL on 517 patients treated with Ch EVAR across USA and Europe, which is a very promising result over a mean follow-up of 17.1 ± 17.4 months.

Depending on the type of endograft used, however, the rate of the consequent type I EL may vary and sometimes may be challenging to fix [34].

Another important issue with Ch EVAR is represented by the risk of chimney graft compression, which can induce stent thrombosis. Donas and Coll. in their multicentric series reported an estimated primary patency rate of 94.9, 91.8, 89.2 and 87.0% at 6 months, 1 year, 2 years and 3 years, respectively [14].

CGT may occur without any clinical sequelae, especially when the chimney stent is placed in a single renal artery. Some patients with occluded renal chimneys may experience a ≥ 25% estimated glomerular filtration rate decline, but when both renal arteries are affected, acute renal failure may occur leading to the need for emergent revascularization or chronic dialysis [17].

Even in case of regular patency, the presence of the chimney stent itself can lead to deformation and alteration of branch vessel anatomy, potentially affecting end-organ perfusion [17].

Some authors have reported different rates of gutter issues and CGT, depending on chimney device selection (self-expanding—SE—vs. balloon-expandable—BE—stent graft; covered vs. uncovered stent graft) [35], but data were not enough to draw any significant conclusion.

The concept of "Endovascular aneurysm sealing" of AAA was developed into the Nellix system (Endologix, Irvine, CA, USA), which was commercially introduced in early 2013 as an alternative endovascular treatment to reduce the reintervention rate after conventional EVAR [36]. Recently, Carpentier et al. [4] reported the results of the one-year pivotal trial of the Nellix system for endovascular aneurysm sealing. Of the 149 patients who completed the 1-year follow-up, out of 150 treated, 4 (3.1%) presented a EL at 1 year (being 1 type Ib and 3 type II). These reported rates seem to be lower than those reported after EVAR [37]. Concerns, however, are rising for long-term results, since a high rate of graft failure has

been observed after EVAS, mostly related to distal migration and stent separation, which often occur 2 years after the procedure [31].

The novel technique has also been recently combined with the chimney technique, exploiting the potential to achieve a better seal at the level of the chimney grafts, and a better incorporation of the chimney stent grafts into the aortic endoprosthesis, with promising reported early results [8]. Long-term results, however, are not yet available. Moreover, the literature lacks clinical studies that compare the postoperative results of Ch EVAS versus Ch EVAR.

Recently, Boersen and Coll [6] performed a benchtop study with the aim to evaluate the geometry of gutter formation and chimney stent graft compression for various Ch EVAR and Ch EVAS configurations. They found that gutter volume was lowest in Ch EVAS in combination with a self-expandable chimney graft, while the degree of chimney graft compression depended on the use of either a balloon-expandable or a self-expandable device. In particular, it was found to be similar between Ch EVAR and Ch EVAS when a balloon-expandable graft was used, and lower in the Ch EVAS configuration when a self-expandable chimney graft was employed.

The potential impact of type I EL and CGT may be then reduced by the presence of the sealing polymer, which could fill the gaps of the "gutters" and could conform more precisely around the chimney stent grafts, without competing with the radial strength of the devices [5].

According to our results, the proportions of both type I EL and CGT occurring after Ch EVAR were similar to those occurring after Ch EVAS, even if the trend seemed to be slightly in favor of Ch EVAS.

Nevertheless, the results are limited by the small number of papers that were available for the assessment both in the Ch EVAR and in Ch EVAS groups, for a short time of follow-up. This could prevent from making any comparative assessment, and additional data with additional follow-up are needed for a proper definition of the complication rates and to address a possible paradigm shift in the use of sealing devices when the chimney technique is employed.

Conclusions

The reported rate of type I EL and TVT occurring after Ch EVAR tended to be slightly higher than those reported after Ch EVAS, even if the difference was not statistically significant.

Compliance with Ethical Standards

Conflict of interest The authors declare that they have no conflict of interest.

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