Midterm Results with the Open Chimney Technique during Endovascular Aneurysm Repair

Eric Ducasse, Caroline Caradu, Coline Brochier, Dominique Midy, Xavier Bérard, Mathieu Poirier, Nicolas Ottaviani

► To cite this version:

Eric Ducasse, Caroline Caradu, Coline Brochier, Dominique Midy, Xavier Bérard, et al.. Midterm Results with the Open Chimney Technique during Endovascular Aneurysm Repair. *JVIR: Journal of Vascular and Interventional Radiology*, 2019, 30, pp.511 - 520.e1. 10.1016/j.jvir.2018.09.013 . hal-03486230

HAL Id: hal-03486230

<https://hal.science/hal-03486230>

Submitted on 20 Dec 2021

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Distributed under a Creative Commons Attribution - NonCommercial| 4.0 International License

Mid-term results with the Open Chimney technique during Endovascular Aneurysm Repair

E. Ducasse^{1*}, C. Caradu¹, C. Brochier¹, D. Midy¹, X. Bérard¹, M. Poirier,² N.
Ottaviani¹

¹ Unit of Vascular Surgery, Pellegrin Hospital, University of Bordeaux, Bordeaux,
France

² Unit of Vascular Surgery, CH de Mont-de-Marsan, Mont-de-Marsan, France

*** Corresponding author : Eric Ducasse**, unit of vascular surgery, université de
Bordeaux, CHU de Bordeaux, France, eric.ducasse@chu-bordeaux.fr

Authors' Note

This study was presented at the 31th annual meeting of the French Society of
Vascular and Endovascular Surgery at Toulouse, France, in June 2017.

Declaration of Conflicting Interests

The author(s) declare no potential conflicts of interest with respect to the
research, authorship, and/or publication of this article.

Funding

The author(s) received no financial support for the research, authorship,
and/or publication of this article.

1 ABSTRACT

2
3 **Purpose.** To report the midterm experience with chimney-endovascular aneurysm
4 repair (Ch-EVAR) with the use of open self-expanding stents for branch vessel
5 preservation.

6 **Materials and Methods.** From July 2010 to May 2017, 67 patients underwent open
7 Ch-EVAR because their proximal landing zones were adjacent to, or covered, the
8 renal or mesenteric arteries (Zones 7-9) and they were not suitable for standard or
9 Fenestrated-EVAR. The proximal landing zone was relocated below the highest renal
10 artery in 46 cases, superior mesenteric artery in 17 and celiac artery in 4, using 84
11 open chimneys (131 stents). A subgroup analysis was performed between an early
12 (2010-2014) and a late time period (2015-2017), 32 patients were treated during the
13 early period and 35 during the late period. In the later period, open chimneys were
14 strengthened by a second self-expanding stent.

15 **Results.** Primary technical success rate was 89.6%. The early mortality rate was
16 9.0%. Median follow-up duration was 13 months (range 1-76 months). The estimated
17 actuarial survival rate was 85.7% in year 1 and 79.2% in year 2 and the estimated
18 patency rate of open chimneys reached 95.2% at 2 years. Aneurysm sac regression
19 >5mm and sac stability rates were 39.0% and 57.6% respectively. Freedom from
20 aneurysm-related reintervention was lower in the late period (log-rank $P = .04$), while
21 type Ia endoleaks tended to be twice as likely.

22 **Conclusion.** Midterm results of open Ch-EVAR show high technical success with
23 acceptable midterm patency and lack of endoleak in appropriately selected patients.
24 The advantages over covered stents are lower profile delivery systems and

25 maintenance of branch vessel patency in early bifurcations and overlying visceral
26 vessels.
27

28 **ABBREVIATIONS**

29 AAA = abdominal aortic aneurysm, CE = European Community, Ch = Chimney, F- =
30 Fenestrated, CT = computed tomography, EVAR = endovascular aneurysm repair,
31 SESs = self-expanding stents, SMA = Superior mesenteric artery.

32 Chimney endovascular aneurysm repair (Ch-EVAR) has emerged as an alternative
33 treatment option for abdominal aortic aneurysms (AAAs) with complex anatomy,
34 lacking an adequate infrarenal sealing zone (1). After the early success of bailout
35 maneuvers for unintentional renal artery coverage (2), parallel grafts have been used
36 as planned repairs to extend the proximal sealing zone, while maintaining side
37 branch patency through covered balloon-expandable stents, covered self-expanding
38 stents (SEEs) or bare SEEs in the “open” chimney technique (3,4).

39 Although the Endurant[®] endograft system (Medtronic Vascular, Santa Rosa, CA,
40 USA) obtained CE-mark approval for Ch-EVAR in 2016, no device has been created
41 solely for this indication with several centers publishing their experience using a
42 variety of devices (5–7).

43 Before CE-mark approval, an open chimney protocol using SEEs was developed for
44 juxtarenal aneurysms with discrepant renal arteries and showed encouraging early-
45 term results (3). The purpose of this study was to report the midterm experience with
46 Ch-EVAR with the use of open SEEs for branch vessel preservation in patients with
47 AAAs who were not suitable candidates for standard or Fenestrated (F)-EVAR.

48

49 **MATERIALS AND METHODS**

50 ***Study Population***

51 This study was developed in accordance with the Declaration of Helsinki and
52 received institutional review board approval. All consecutive patients admitted for
53 EVAR between July 2010 and May 2017 were evaluated for inclusion if they had one
54 or more parameters of a hostile neck and if they were not suitable candidates for the
55 only CE–approved fenestrated endograft at the time (Zenith Fenestrated[®]; Cook
56 Medical, Melbourne, Australia). The new landing zone had to offer parallel-shaped

57 aortic walls $\geq 10\text{mm}$ in length and $\leq 32\text{mm}$ in diameter. The inclusion criteria are
58 detailed in Appendix Table 1.

59 In total, 67 patients (56 male) underwent open Ch-EVAR because their proximal
60 landing zones were adjacent to, or covered, the renal or mesenteric arteries (zones 7
61 through 9 according to the Society for Vascular Surgery classification. Per that
62 classification, zone 7 covers the SMA and ends proximal to renal arteries, zone 8
63 covers at least one renal artery and zone 9 is infrarenal) (8). Table 1 summarizes
64 patient demographics. Seven patients (10.4%) presented with acute aortic syndrome
65 but remained hemodynamically stable until surgery. The proximal landing zone was
66 relocated below the highest renal artery in 46 cases, the SMA in 17 cases and the
67 celiac artery in 4 cases, using 84 open chimneys created with 131 SESs. The median
68 length of improved landing-zone was 17mm (range 7-26) and the median follow-up
69 duration was 13 months (range 1-76) (early group, 31 [range 6-76], and late group, 8
70 [range 1-37]). The study was divided into an early period (from 2010 to 2014) and a
71 late period (from 2015 to 2017). The later time period differed by the extent of
72 endovascular repair to more complicated designs and the reinforcement of open
73 chimneys by a second SES (15). Thirty-two patients were treated during the early
74 period and 35 during the late period (Fig 1). There was no significant difference in
75 patients' demographics between the 2 study periods except for a significantly lower
76 number of current smokers during the late period ($P = .048$).

77

78 ***Procedure Details***

79 Forty-two procedures were performed at the main study center and 25 at 12 other
80 European vascular centers, where the same team was tutoring for complex aortic
81 repairs. During the study period, 372 EVARs were performed. Device sizing was

provided by the primary surgeon on a dedicated imaging workstation (DxWin® Ver. 6.3e14, Medasys Inc, Clamart, France) using high-resolution CT scans. Procedures were performed in the operating room under general anesthesia and systemic heparinization (0.5mg/kg) as previously described (3,9). Briefly, the aortic graft was introduced from a femoral access. A bare SES was placed into the target vessel from an upper brachial access over a superstiff 0.035" Rosen wire (CookEurope, Bjaeverskov, Denmark). Chimney grafts were chosen to extend ≥ 1 cm above the covered part of the aortic graft into the free-flow section, as per the actual instructions for use of the CE-mark approval, and to leave ≥ 2 cm within the target vessel. The median diameters of the open chimneys were 9mm (range, 8-10) and 6mm (range, 5-8), with a median length of 60mm (range, 40-60) and 40mm (range, 20-80) for the superior mesenteric artery (SMA) and the renal arteries, respectively.

94

Zenith® (Cook Medical, Melbourne, Australia) and Lifestent® (Bard Peripheral Vascular, Tempe, AZ, USA) devices were progressively replaced by Endurant® and Complete SE® devices (Medtronic, Minneapolis, MN, USA) during the late period. Complete SE® stents were preferred because of enhanced visibility and a triaxial design, which stabilizes the sheath by reducing friction forces, and ultimately leads to an easier and more accurate deployment of the chimney. A significantly greater degree of oversizing was also applied to the aortic graft during the late period ($P = .006$) in reaction to prior investigations (9,10) to allow the fabric to mold around the chimneys and limit the risk of type Ia endoleaks (11). After extrinsic compression due to device-to-device and device-to-vessel interaction was reported for 2 patients in the early period of this study and in other studies (15), open chimneys were strengthened by a second SES of the same diameter and length to increase their radial force. The

endovascular repair was also extended to more complicated designs. Every renal artery or SMA close to the proximal landing zone was considered a target artery and a kissing balloon technique was not used since the implanted stents were only SESs.

Post-Operative Management

The patients were admitted to the intensive care unit for 0 to 31 days and stayed in the hospital during a median of 7 days (range, 1-372). A subcutaneous adjusted-dose of unfractionated heparin was administered to match a plasma heparin level, as expressed by anti-Xa activity, of 0.4 to 0.8 UI/mL for 48 hours, then patients were treated with dual antiplatelet therapy and statins for 3 months, followed by single antiplatelet therapy in the long term if not otherwise indicated.

In the absence of specific contraindications, follow-up contrast enhanced CT scans were performed before discharge, then at 6 months and 12 months, and yearly thereafter. In addition, a Duplex ultrasound was performed before discharge and serum creatinine levels were monitored before each CT scan.

Outcome Measures

Procedural and periprocedural factors were assessed, endpoints of this investigation included initial technical success and complications, all-cause mortality, freedom from secondary intervention and endoleak, and the estimated patency rates of open chimneys as well as sac enlargement. Definitions complied with the reporting standard (13). Primary technical success was defined by successful deployment of the devices in the absence of surgical conversion or mortality, type I or III endoleaks, or graft occlusion. An endoleak was defined by the persistence of blood flow outside

the lumen of the endoluminal graft but within the aneurysm sac, as determined by the final angiogram or any of the follow-up CT scans. Additionally, type Ia endoleaks were further characterized, according to the definition provided by Ullery *et al.*, into “long” and “short” gutter endoleaks (14). A «hostile abdomen» was defined as an abdomen with persistent loss of natural free spaces between intra-abdominal organs and structures of abdominal compartment, pathological changes of their normal anatomical proportions and adhesions as a consequence of previous laparotomies, peritonitis, pancreatitis, abdominal trauma, intestinal Crohn’s disease or extensive radiation therapy.

Statistical Analysis

GraphPad Prism v7.0 (GraphPad Inc, San Diego, Calif) was used for statistical analysis. Data are shown as basic descriptive statistics, such as median (range) or means for continuous variables and proportions and frequencies for categorical variables. A subgroup analysis was performed between an early (from 2010 to 2014) and later time period (from 2015 to 2017). Normality of data was tested with the Shapiro-Wilk test. Differences between groups were evaluated with a contingency table analysis and a χ^2 test (categorical variables), Mann-Whitney or t tests (continuous variables) as appropriate. Kaplan-Meier analysis was used to assess midterm follow-up outcomes (survival, freedom from aneurysm-related mortality, reintervention, and target vessel’s patency) and comparisons between groups were assessed with the log-rank test. Statistical significance was assumed at $p < .05$.

RESULTS

Initial Technical Success and Complication

Anatomic Characteristics and periprocedural factors are reported in Table 2. Primary technical success rate of open Ch-EVAR was 89.6% (early group, 93.8% vs. late group, 85.7%; $P = .29$). No procedure-related death or open conversion were reported and every target vessel was successfully reconstructed. The mean ratio of open chimneys per patient was 1.2 (early group, 1.1 vs. late group, 1.4), which led to a significant increase in operating time during the late period (total, 120 [range, 70-315]) (early group, 108 [range, 70-290] vs. late group, 164 [range, 81-315]; $P = .004$). Perioperative successful aneurysm exclusion was achieved in 60 patients (89.6%). Seven “short” type Ia endoleaks (early group, 2 [6.3%] vs. late group, 5 [14.3%]; $P = .29$) and 11 type II endoleaks (16.4%) (early group, 6 [18.8%] vs. late group, 5 [14.3%]; $P = .63$) were detected at the end of the procedures. The initial CT scan was performed at a median interval of 4 days post Ch-EVAR (range 0-30 days) and open chimneys helped preserve important overlying visceral arteries in 10 cases (14.9%) and branch divisions in 5 cases (7.5%) (Table 3).

According to the reporting standard (13), 10 mild, 7 moderate and 7 severe complications developed in 22 patients (32.8%) (Table 4). The in-hospital and early postoperative (30-day) mortality rate was 9% (8.3% in asymptomatic patients [5/60]) (early group, 4 [12.5%] and 5 [15.6%] vs. late group, 2 [5.7%] and 1 [2.9%]; $P = .34$ and $P = .07$ respectively). Patients died of heart failure ($n = 1$), myocardial infarction ($n = 2$), pneumonia ($n = 1$), multiple organ failure ($n = 2$, in patients with symptomatic aneurysms) and stroke ($n = 1$).

Mid-Term Outcomes

The estimated actuarial survival rate was 85.7% and 79.2% at 1 and 2-year (early

group, 84.4% and 76.5% vs. late group, 84.7%; log-rank $P = .53$). Six patients died during the follow-up, of heart failure ($n = 3$), pneumonia ($n = 2$) and aneurysm-related cause ($n = 1$). The patient whose death was potentially aneurysm-related was a 74-year-old male. He was treated in emergency for a ruptured aneurysm with an aorto-enteric fistula and died 2 months after the initial procedure.

Estimated 2-year primary patency of open chimneys was 95.2% (early group, 94.1% vs. late group, 95.9%; log-rank $P = .70$) (Fig 2). There were 4 occlusions of open chimneys to the renal arteries. During the early period, one was incidentally discovered 2 days after the initial procedure on the control CT scan in a patient already on dialysis; and one occurred at 1 month in a patient who suddenly suffered from anuria and neurologic degradation after a cardio-embolic event and died in the aftermath. During the late period, two patients manifested by acute flank pain 17 days and 1 month after the initial procedure respectively, they both led to a failed attempt to rescue them, leading to a severe deterioration of the renal function and dialysis in the first patient, while the second did not exhibit any long-term consequence.

Eight renal infarcts were observed over 6 patients (9.0%) (early group, 5 infarcts/4 patients [12.5%] vs. late group, 3/2 [5.7%]; $P = .34$). The patient in the early group, who presented with bilateral renal infarcts, had a “shaggy” distal aorta and the postoperative CT scan showed multiple distal emboli in the territory of both renal and splenic arteries despite a preserved patency of the main branches, his renal function showed significant improvement during follow-up. Two out of 12 patients experiencing acute kidney injury required temporary dialysis (both in the early group)

and 2 required permanent dialysis (1 in each group [3.1% vs. 2.9%]).

No statistical difference was observed in outcome measures, except for significantly lower rates of freedom from aneurysm-related reintervention in the late period compared to the early period (log-rank $P = .04$) (Table 6), while “short” type Ia endoleaks tended to be twice as likely. However, the overall number of type 1A endoleak did not differ significantly between the two study periods ($P = .87$). Overall, 8 type 1A endoleaks (/52 patients, 15.4%) vs. 4 (/15 patients; 26.7%; $P = .44$), including 1 “long” gutter endoleak (1.9%) vs. 3 (20.0%; $P = .03$) and 7 “short” gutter endoleaks (13.5%) vs. 1 (6.7%; $P = .67$), were detected in patients with 1 open chimney vs. patients with 2 or 3 open chimneys, respectively. Two patients exhibited persistent “short” gutter endoleaks and remain under surveillance with a stability of their sac at 78mm at 11 month- and 48mm at 43 month-follow-up, respectively (16). Type Ia endoleak outcomes are reported in Table 5. Four type II endoleaks spontaneously disappeared during the early period (1 at 3 months, 1 at 4 months, 1 at 11 months and 1 at 16 months) and 2 during the late period (1 at 1 month and 1 at 22 months). A sac regression > 5mm occurred in 39.0% of the patients (early group, 12/28 and late group, 11/31) and sac stability occurred in 57.6% (early group, 14/28 vs. late group, 20/31).

DISCUSSION

This article describes the mid-term follow-up results of the largest series of Ch-EVAR with the exclusive use of bare SESs for the construction of chimneys. A comparison was drawn between an early and later time period, when the endovascular repair was extended to more complicated designs and open chimneys were reinforced by a

second SES. Importantly, the number of detected “short” type Ia endoleaks tended to be twice as likely during the late period. This difference could be related to an increase in their detection during the final angiogram, rather than an increase in their number. Nonetheless, the 10.4% rate of early gutter-related type Ia endoleak is within the 0 to 37.5% range noted in previous reports (10,15,17,18). Additionally, a decrease in the rates of late type Ia endoleak and reintervention were reported for a mean new proximal neck length of 18.7 ± 6.3 mm (range 6-58) in the PROTAGORAS study (10), which led to the conclusion that a new proximal landing zone >15mm is necessary to increase the potential for spontaneous gutter thrombosis (18). This corroborates with the use of a median neck length of 17 mm in this study. Ullery et al. reported a 65.2% rate of spontaneous resolution of these “gutter” endoleaks within a year, and over a 88% rate by 18 months (14). For those persisting, coil or polymer embolization (10,14,15) and repeat balloon molding offer encouraging results. During the late period of this study, more aggressive treatments of persisting type Ia endoleaks through the gutters could explain the significant decrease in freedom from aneurysm-related reintervention, since the majority of secondary reinterventions were chimney- or endoleak-related (2 and 7/6 patients, including 4 successful treatments of type Ia endoleaks). Altogether, this might explain the high rate of aneurysm sac regression or stability in this series (96.6%) compared to the literature results (> 85%) (10,20). It is, however, important to consider the fact that the transformation of an open chimney into a covered chimney is usually necessary to avoid branch thrombosis and simplify the embolization process. Besides, the secondary cannulation of an open chimney over its entire length might prove difficult depending on its angulation.

257 This study showed a higher rate of open chimneys' occlusions when combined with
258 stainless steel aortic grafts (Zenith® devices) (3 occlusions, 6.4%), compared to
259 nitinol aortic grafts (Endurant® devices) (1 occlusion secondary to a cardio-embolic
260 event, 3.4%). Nitinol endoskeletons exhibit more elasticity and exert a continuous
261 and low outward force. Consistently, a sub analysis of the PERICLES registry
262 recently reported a 1.8-fold increase of chimney occlusion in patients treated with
263 stainless steel devices and balloon-expandable covered stents relative to other
264 chimney stents (HR, 4.0; 95% CI, 0.85-18.84; $P = .08$) (5). Nitinol aortic endografts
265 might be more suited for Ch-EVAR. Furthermore, a device with a suprarenal bare
266 stent fixation helps anchor the chimney graft up against the aortic wall, which could
267 limit the risks of aortic graft migration, parallel-graft horizontalization and branch
268 occlusion (15).

269
270 The use of bare SESs for the construction of chimneys have some undeniable
271 advantages, especially when using new generation stents, which offer higher
272 flexibility and greater stability during release with smaller delivery systems (down to
273 4-F for 1 open chimney, 6 to 9-F for 2) in comparison with previous generations.
274 These features are of paramount importance, since target arteries are mostly
275 cannulated from an upper limb access, especially in angulated anatomies (3,9) and
276 hostile iliac accesses (21), which led to their acceptance as an alternative in selected
277 elective cases (15,17). This allows for up to 3 open chimneys to be deployed from a
278 low profile single brachial artery access, when the use of the larger diameter covered
279 stents requires an axillary or contralateral access, which may increase the risk of
280 stroke in relation to aortic arch navigation (22). Additionally, bare stents are available
281 in longer lengths than covered balloon-expandable stents. Finally, the position of the

chimneys is hard to anticipate and it can adopt an anterior or posterior helicoidal position (23). Thus, chimneys can sometimes land in front of the ostium of important visceral vessels (Fig 3), where the use of covered stents would have led to their impingement or occlusion. Bare stents offer persisting blood flow through their struts, which could help preserve the patency of close overlying visceral vessels. Likewise, the stent can be pushed further inside the target vessel for safer anchoring without losing the perfusion of any of the branches, even when there is an early bifurcation (i.e. emergence of segmental branches $\leq 2\text{cm}$ from origin). Recently, some reports noted a trend toward an increase in type Ia endoleaks with the use of SESs compared to balloon-expandable stents (15,16). However, these may be the result of selection bias, since SESs were mostly reserved for cases with excessive branch vessel angulation.

Finally, the patency rates of these open chimneys (95.2% for a mean imaging follow-up of 19.3 months) are comparable to the ones previously reported in the PROTAGORAS study, which analyzed the combination of the Endurant[®] graft with covered balloon-expandable stents, and concluded to a primary patency rate of 95.7% (8 occluded chimneys) for a mean follow-up duration of 24.6 months (17). This supports the theory that the covered nature of the stent does not confer any benefit in terms of patency in this indication (17). Additionally, the PROTAGORAS study reported a 93.1% rate of freedom from chimney graft-related reintervention, which compares favorably to the 97.6% rate of this series (2 chimney graft-related reinterventions). Importantly, 30-day mortality was high compared to other series (13,17), but might be partially explained by a larger number of patients with coronary artery disease and unfavorable anatomies compared to standard or F-EVAR series. Nonetheless, all-cause mortality was 19.4% (no late aortic rupture), which compares

307 well to the 17.2% reported in the PROTAGORAS study (1 procedure-related late
308 aortic rupture).

309 The number of patients included in this study remains low, which could have led to
310 insufficient statistical power. Thus, this study could not demonstrate a definite
311 advantage in the use of a second SES to reinforce the open chimney and this point
312 will truly deserve further investigations in order to determine if this could help
313 preserve the patency of the chimneys, as advocated by some literature results
314 (11,15).

315 Finally, because the alternatives to Ch-EVAR in the elective setting could offer more
316 durable outcomes, selection criteria should remain strict and no compromise should
317 be made on the sealing area.

318 In conclusion, midterm results of open Ch-EVAR show high technical success with
319 acceptable midterm patency and lack of endoleak in appropriately selected patients.
320 The advantages over more recently introduced covered stents for this purpose are
321 lower profile delivery systems (potentially reducing complications relative to upper
322 limb access) and maintenance of branch vessel patency in early bifurcations and
323 overlying visceral vessels. Nonetheless, the reintervention rates remain high and
324 long-term follow-up will determine the durability of this approach.

325 REFERENCES

- 326 1. Patel RP, Katsargyris A, Verhoeven ELG, Adam DJ, Hardman JA.
 327 Endovascular aortic aneurysm repair with chimney and snorkel grafts: indications,
 328 techniques and results. *Cardiovasc Intervent Radiol*. 2013 Dec;36(6):1443–51.
- 329 2. Greenberg RK, Clair D, Srivastava S, Bhandari G, Turc A, Hampton J, et al.
 330 Should patients with challenging anatomy be offered endovascular aneurysm repair?
 331 *J Vasc Surg*. 2003 Nov;38(5):990–6.
- 332 3. Ducasse E, Lepidi S, Brochier C, Deglise S, Berard X, Alberti D, et al. The
 333 'open' chimney graft technique for juxtarenal aortic aneurysms with discrepant renal
 334 arteries. *Eur J Vasc Endovasc Surg Off J Eur Soc Vasc Surg*. 2014 Feb;47(2):124–
 335 30.
- 336 4. Lachat M, Veith FJ, Pfammatter T, Glenck M, Bettex D, Mayer D, et al.
 337 Chimney and periscope grafts observed over 2 years after their use to revascularize
 338 169 renovisceral branches in 77 patients with complex aortic aneurysms. *J Endovasc*
 339 *Ther Off J Int Soc Endovasc Spec*. 2013 Oct;20(5):597–605.
- 340 5. Scali ST, Beck AW, Torsello G, Lachat M, Kubilis P, Veith FJ, et al.
 341 Identification of optimal device combinations for the chimney endovascular aneurysm
 342 repair technique within the PERICLES registry. *J Vasc Surg*. 2018 Jan 27;
- 343 6. Mestres G, Uribe JP, García-Madrid C, Miret E, Alomar X, Burrell M, et al. The
 344 best conditions for parallel stenting during EVAR: an in vitro study. *Eur J Vasc*
 345 *Endovasc Surg Off J Eur Soc Vasc Surg*. 2012 Nov;44(5):468–73.
- 346 7. Lachat M, Bisdas T, Rancic Z, Torsello G, Mayer D, Gil-Sales J, et al.
 347 Chimney endografting for pararenal aortic pathologies using transfemoral access and
 348 the lift technique. *J Endovasc Ther Off J Int Soc Endovasc Spec*. 2013
 349 Aug;20(4):492–7.
- 350 8. Fillinger MF, Greenberg RK, McKinsey JF, Chaikof EL, Society for Vascular
 351 Surgery Ad Hoc Committee on TEVAR Reporting Standards. Reporting standards for
 352 thoracic endovascular aortic repair (TEVAR). *J Vasc Surg*. 2010 Oct;52(4):1022–33,
 353 1033.e15.
- 354 9. Caradu C, Morin J, Poirier M, Midy D, Ducasse E. Monocentric evaluation of
 355 chimney versus fenestrated endovascular aortic repair for juxta-renal abdominal
 356 aortic aneurysm. *Ann Vasc Surg*. 2017 Feb 1;
- 357 10. Donas KP, Torsello GB, Piccoli G, Pitoulas GA, Torsello GF, Bisdas T, et al.
 358 The PROTAGORAS study to evaluate the performance of the Endurant stent graft for
 359 patients with pararenal pathologic processes treated by the chimney/snorkel
 360 endovascular technique. *J Vasc Surg*. 2016 Jan;63(1):1–7.
- 361 11. Mestres G, Yugueros X, Apodaka A, Urrea R, Pasquadibisceglie S, Alomar X,
 362 et al. The best in vitro conditions for two and three parallel stenting during
 363 endovascular aneurysm repair. *J Vasc Surg*. 2017 Oct;66(4):1227–35.
- 364 12. Voskresensky I, Scali S, Feezor RJ, Fatima J, Giles KA, Tricarico R, et al.
 365 Outcomes of Thoracic Endovascular Aortic Repair Using Aortic Arch Chimney Stents
 366 in High Risk Patients. *J Vasc Surg*. 2017 Jul;66(1):9-20.e3.
- 367 13. Chaikof EL, Blankensteijn JD, Harris PL, White GH, Zarins CK, Bernhard VM,
 368 et al. Reporting standards for endovascular aortic aneurysm repair. *J Vasc Surg*.
 369 2002 May 1;35(5):1048–60.
- 370 14. Ullery BW, Tran K, Itoga NK, Dalman RL, Lee JT. Natural history of gutter-
 371 related type Ia endoleaks after snorkel/chimney endovascular aneurysm repair. *J*
 372 *Vasc Surg*. 2017 Apr;65(4):981–90.
- 373 15. Donas KP, Lee JT, Lachat M, Torsello G, Veith FJ, PERICLES investigators.

Collected world experience about the performance of the snorkel/chimney endovascular technique in the treatment of complex aortic pathologies: the PERICLES registry. *Ann Surg.* 2015 Sep;262(3):546–53; discussion 552-553.

16. Donas KP, Pecoraro F, Torsello G, Lachat M, Austermann M, Mayer D, et al. Use of covered chimney stents for pararenal aortic pathologies is safe and feasible with excellent patency and low incidence of endoleaks. *J Vasc Surg.* 2012 Mar;55(3):659–65.

17. Hiramoto JS, Chang CK, Reilly LM, Schneider DB, Rapp JH, Chuter TAM. Outcome of renal stenting for renal artery coverage during endovascular aortic aneurysm repair. *J Vasc Surg.* 2009 May 1;49(5):1100–6.

18. Moulakakis KG, Mylonas SN, Avgerinos E, Papapetrou A, Kakisis JD, Brountzos EN, et al. The chimney graft technique for preserving visceral vessels during endovascular treatment of aortic pathologies. *J Vasc Surg.* 2012 May;55(5):1497–503.

19. Donselaar EJ, van der Vijver-Coppen RJ, van den Ham LH, Lardenoye JWHP, Reijnen MMPJ. EndoAnchors to Resolve Persistent Type Ia Endoleak Secondary to Proximal Cuff With Parallel Graft Placement. *J Endovasc Ther.* 2016 Feb 1;23(1):225–8.

20. Donas KP, Pecoraro F, Bisdas T, Lachat M, Torsello G, Rancic Z, et al. CT angiography at 24 months demonstrates durability of EVAR with the use of chimney grafts for pararenal aortic pathologies. *J Endovasc Ther Off J Int Soc Endovasc Spec.* 2013 Feb;20(1):1–6.

21. Caradu C, Bérard X, Midy D, Ducasse E. Influence of Anatomic Angulations in Chimney and Fenestrated Endovascular Aneurysm Repair. *Ann Vasc Surg.* 2017 Feb 28;

22. Cui X, Li Y, Liu J, He S, Liu M. Aortic arch atheroma and the risk of stroke: a meta-analysis. *J Evid-Based Med.* 2014 Aug;7(3):185–91.

23. Tran K, Ullery BW, Itoga N, Lee JT. Polar orientation of renal grafts within the proximal seal zone affects risk of early type Ia endoleaks after chimney endovascular aneurysm repair. *J Vasc Surg [Internet].* 2017 Oct 23 [cited 2018 Feb 28];0(0). Available from: [http://www.jvascsurg.org/article/S0741-5214\(17\)32103-1/fulltext](http://www.jvascsurg.org/article/S0741-5214(17)32103-1/fulltext)

Figure 1. Flow Chart

Covered arteries (X)

Open chimneys (arrowheads)

Figure 2. Kaplan-Meier curves. **(a)** Overall survival. **(b)** Freedom from aneurysm-related reintervention. **(c)(d)** Subgroup analysis between an early and later time period (early period : from 2010 to 2014 and late period : from 2015 to 2017, when chimney grafts were reinforced by a second self-expanding stent). **(c)** Overall survival. **(d)** Freedom from aneurysm-related reintervention. **(e)** Aneurysm sac evolution relative to the maximum transverse diameter (Aneurysm enlarged >5mm between two CT scan measures in 2 patients (3.0%), remained stable with variations between -5 and 5mm in 34 patients (50.7%) and decreased >5mm in 23 patients (34.3%)).

FU = Follow-up.

Figure 3. Images from patients with AAA treated with open chimneys. **(a)** Images from a 77-year-old male patient with a AAA treated with an open chimney to the left renal artery. The contrast-enhanced CT scan obtained 2 years after the procedure shows the traditional conformation of the chimney graft, the aortic endograft and the aortic wall, leaving only a small “physiologic” blind gutter space. **(b)(c)** Images from an 80-year old male patient treated with open chimneys to both renal arteries. **(b)** The contrast-enhanced CT scan obtained 2 years after the procedure shows the positioning of the upper part of both open chimneys in front of the ostium of the

superior mesenteric artery. Both renal arteries and the superior mesenteric artery remain patent. **(c)** Three D reconstruction confirms the positioning of the stents in front of the superior mesenteric artery, and the preserved patency of the renal arteries and the superior mesenteric artery. **(d)(e)(f)(g)** Images from a patient with a history of prior infra-renal endovascular reconstruction treated with open chimneys to both renal arteries to correct a type Ia endoleak during the late period. **(d)** Immediate post-operative contrast-enhanced CT scan shows the persistence of a type Ia endoleak (arrowhead) after the open chimney procedure. **(e)** MIP of the immediate post-operative contrast-enhanced CT scan shows a “long” gutter endoleak (arrowhead) relative to the left renal artery’s gutter, going into the aneurysm sac. **(f)** Angiogram obtained during a secondary procedure confirms the localization of the type Ia endoleak (arrowhead). **(g)** Angiogram obtained 16 months after the embolization procedure shows the absence of any residual type Ia endoleak through the gutter.

AAA = abdominal aortic aneurysm; MIP = Maximum Intensity Projection

113 consecutive patients
with 1 × Open Chimney ×
From July 2010 to May 2017

× Open Chimney ×
× Covered chimney

n=7

× Open Chimney ×
× F-EVAR

n=26

Isolated × Open Chimney × technique

Stenting zone :

1 × Open
Chimney ×

1 × Open
Chimney ×

2 × Open
Chimney ×

1 × Open
Chimney ×

1 × Open
Chimney ×

	n	n	n	n	n	n
Stent-coverage	57	40	0	18	3	1
Early period (2010-2013)*	19	10	1	1	1	0
Late period (2013-2017)†	38	30	0	17	2	1

F-EVAR = fenestrated endovascular aortic repair; SMA = superior mesenteric artery; CA = celiac artery;
RRA = right renal artery; LRA = left renal artery.

* Coverage of 1 RRA was planned before surgery because of an atrophic kidney

† Coverage of 3 LRA and 1 RRA was planned before surgery because of atrophic kidneys in 2 cases, and because of a solitary left kidney in 2 other cases. In this subgroup, open chimneys were reinforced with a second self-expanding stent.

Table 1. Patient Characteristics and Demographics

Characteristic	Total (n = 67)	Early period (2010-2014) (n = 32)	Late period (2015-2017) (n = 35)	P Value*
Age, yr	77 (62-88)	76 (63-88)	80 (62-88)	.17
Male	56 (83.6%)	27 (84.4%)	29 (82.9%)	.87
ASA class				.97
III	43 (64.2%)	20 (62.5%)	23 (65.7%)	
IV	4 (6.0%)	5 (15.6%)	5 (14.3%)	
Diabetes	8 (11.9%)	4 (12.5%)	4 (11.4%)	.96
CAD	37 (55.2%)	20 (62.5%)	17 (48.6%)	.38
COPD	19 (28.4%)	8 (25.0%)	11 (31.4%)	.47
Current smoker	19 (28.4%)	13 (40.6%)	6 (17.1%)	.048
Preoperative renal disease	27 (40.3%)	15 (46.9%)	12 (34.3%)	.30
Hostile abdomen	12 (17.9%)	4 (12.5%)	8 (22.9%)	.23
Prior aortic surgery	8 (11.9%)	3 (9.4%)	5 (14.3%)	.54
Type Ia EL from prior EVAR	4 (6.0%)	0 (0.0%)	4 (11.4%)	
Para-anastomotic aneurysm	2 (3.0%)	1 (3.1%)	1 (2.9%)	
Thoracic endograft	2 (3.0%)	2 (6.3%)	0 (0.0%)	
Clinical status				
Symptomatic [†]	7 (10.4%)	4 (12.5%)	4 (11.4%)	.96
Penetrating ulcer	6 (9.0%)	2 (6.3%)	4 (11.4%)	.47
Rapidly growing or $\theta \geq 70\text{mm}$	15 (22.4%)	8 (25.0%)	7 (20.0%)	.63

All values with ranges are median (range).

ASA = american society of anesthesiologists; CAD = coronary artery disease; COPD = chronic obstructive pulmonary disease; BMI = body mass index; EL = Endoleak; EVAR = endovascular aortic repair; θ = Maximum Transverse Diameter.

* the p values refer to the comparison between the two study periods.

[†] acute aortic syndrome with either painful aneurysms with stable patients at admission or contained ruptures on Computed Tomographic Angiography.

Table 2. Anatomic Characteristics and periprocedural factors

Characteristic	Entire Cohort	Early period (2010-2014)	Late period (2015-2017)	P value*
Aortic anatomy, mm				
Maximum aneurysm diameter	59 (43-110)	60 (43-110)	59 (47-110)	.46
Infrarenal neck length	3 (0-16)	4 (0-16) [†]	3 (0-16) [†]	.89
Length of New sealing zone	17 (7-26)	18 (7-26)	14 (10-24)	.63
Aortic graft				
Zenith [®] (Cook)	39 (58.2%)	27 (84.4%)	12 (34.3%)	< .0001
Endurant [®] (Medtronic)	22 (32.8%)	4 (12.5%)	18 (51.4%)	.0005
AFX [®] (Endologix)	1 (1.5%)	1 (3.1%)	0 (0.0%)	
C3 [®] (Gore)	5 (7.5%)	0 (0.0%)	5 (14.3%)	
Oversizing, %	19 (13-33)	17 (13-28)	22 (13-33)	.006
Aorto-biiliac graft	58 (86.6)	28 (87.5%)	30 (85.7%)	.83
Aorto-mono iliac graft+femoro-femoral bypass	4 (6.0%)	3 (9.4%)	1 (2.9%)	.27
Proximal Cuff	5 (7.5%)	1 (3.1%)	4 (11.4%)	.20
Hypogastric artery embolization	8 (11.9%)	5 (15.6%) [‡]	3 (8.6%)	.38
Number of Target vessels	83 (100%)	34 (100%) [§]	49 (100%) **	
SMA	4 (4.8%)	1 (2.9%)	3 (6.1%)	
Left renal artery	53 (63.9%)	25 (73.5%)	28 (57.1%)	
Right renal artery	26 (31.3%)	8 (23.5%)	18 (36.7%)	
Chimney grafts				
Complete SE [®] (Medtronic)	28 (33.7%)	3 (8.8%)	25 (51%) ^{††}	< .0001
Lifestent [®] (Bard)	23 (27.7%)	16 (47.1%)	7 (14.3%) ^{††}	.004
Absolute Pro [®] (Abbott)	16 (19.3%)	5 (14.7%)	11 (22.4%) ^{††}	.13
Astron Pulsar [®] (Biotronik)	7 (8.4%)	4 (11.8%)	3 (6.1%) ^{††}	.61
Protégé EverFlex [®]	3 (3.6%)	1 (2.9%)	2 (4.1%) ^{††}	.62
Epic [®] (Boston Scientific)	2 (2.4%)	2 (5.9%)	0 (0.0%)	
Zilver [®] (Cook)	1 (1.2%)	0 (0.0%)	1 (2%) ^{††}	
Luminexx [®] (Bard)	1 (1.2%)	1 (2.9%)	0 (0.0%)	
Misago [®] (Terumo)	1 (1.2%)	1 (2.9%)	0 (0.0%)	
S.M.A.R.T [®] (Cordis)	1 (1.2%)	1 (2.9%)	0 (0.0%)	
Chimney Access				
Right and Left brachial arteries	6 (9%)	1 (3.1%)	5 (14.3%)	
Left brachial artery	61 (91%)	31 (96.9%)	30 (85.7%)	.11
Periprocedural factors				
Fluoroscopy time, min	37 (17-91)	34 (15-90)	43 (23-91)	.22
Kerma area product, Gy/cm ²	110 (25-227)	110 (29-185)	116 (25-227)	.76
Contrast volume, mL	95 (45-180)	99 (45-180)	95 (45-150)	.50

All values with ranges are median (range).

SMA = superior mesenteric artery; ICU = intensive care unit.

* the p values refer to the comparison between the two study periods.

[†] one patient presented an inverted tapered neck of 16mm

[‡] 1 bilateral (right side was treated 3 months before EVAR).

[§] Coverage of 1 right renal artery was chosen to be performed pre-operatively because of atrophic kidney

** Coverage of 3 left and 1 right renal artery was chosen to be performed pre-operatively because of atrophic kidneys and two patients already presented with a solitary left kidney.

In accordance with the SVS consensus, only renal arteries <4mm in diameter and supporting <1/3 of renal parenchyma were considered for ostium coverage.

^{††} During the late study period chimney grafts were always reinforced with a second self-expanding stent of the same brand, diameter and length, to ease comparison with the early study period only one stent was reported for each target vessel.

Table 3. Open chimneys and preservation of important branch vessels

	Target vessel of the open chimney	Branch vessel at risk*	Patients (n = 30)
Ostium	SMA	Coeliac Trunk	10 (14.9%)
	Right Renal Artery	SMA and Coeliac Trunk	2 (3.0%)
	Left and Right Renal Arteries	SMA and Coeliac Trunk	1 (1.5%)
	Left Renal Artery	SMA	1 (1.5%)
	Left and Right Renal Arteries	SMA	3 (4.5%)
	Right Renal Artery	SMA	2 (3.0%)
		Left Renal Artery	1 (1.5%)
Branch Division			5 (7.5%)
	SMA		1 (1.5%)
	Left Renal Artery		4 (6.0%)

SMA = superior mesenteric artery.

* Branch vessel in front of which the open chimney landed after deployment, in a configuration that would have resulted in a significant stenosis or occlusion of the branch if the stent used for the construction of the chimney had been a covered stent.

At latest follow-up all the branch vessels were still preserved.

Table 4. Early (30-day) complications

Characteristic	Total (n = 67)	Early period (2010-2014) (n = 32)	Late period (2015-2017) (n = 35)
Mild	10 (14.9%)	4 (12.5%)	6 (17.1%)
access-site hematomas	6 (9.0%)	1 (3.1%)	5 (14.3%)
femoral dissection	1 (1.5%)	1 (3.1%)	0 (0.0%)
false-aneurysms	1 (1.5%)	1 (3.1%)	0 (0.0%)
lymphoceles	2 (3.0%)	1 (3.1%)	1 (2.9%)
Moderate	7 (10.4%)	4 (12.5%)	3 (8.6%)
false-aneurysms	1 (1.5%)	0 (0.0%)	1 (2.9%) *
buttock claudication	1 (1.5%)	1 (3.1%) †	0 (0.0%)
iliac limb occlusion	1 (1.5%)	1 (3.1%) ‡	0 (0.0%)
iliac rupture	1 (1.5%)	0 (0.0%)	1 (2.9%) §
pneumonia	3 (3.6%)	2 (6.3%)	1 (2.9%)
Severe	7 (10.4%)	6 (18.8%)	1 (2.9%)
iliac limb occlusion	2 (3.0%)	2 (6.3%) ‡	0 (0.0%)
iliac rupture	1 (1.5%)	1 (3.1%) §	0 (0.0%)
pneumonia	1 (1.5%)	1 (9.4%)	0 (0.0%)
embolic stroke	3 (3.6%)	2 (6.3%) **	1 (2.9%) ††
30- day Mortality	6 (9.0%)	5 (15.6%)	1 (2.9%)

* patient required reintervention

† patient presented with progressive pain in the right gluteus, which progressed into rhabdomyolysis and acute renal failure, after a planned occlusion of the right internal iliac for common iliac aneurysm. His serum creatinine levels almost went back to the preoperative values during follow-up and he was left suffering from moderate right buttock claudication.

‡ secondary to a kink of the common and external iliac arteries following endograft positioning, and successfully treated by thrombectomy and uncovered stent delivery

§ treated by covered stenting

** related to the upper approach

†† related to cardiac embolism

Table 5. Overview of type Ia Endoleak Outcomes

Patient	First appearance	Imaging aspect	Open Chimney	Last control
Early period (2010-2014)				
6	40 month FU	"Short" gutter endoleak	1	Sealed spontaneously at 40 months
7	40 month FU	"Short" gutter endoleak	1	Present until death from septic shock over pneumonia
13	Control angiogram	"Short" gutter endoleak	1	Sealed spontaneously at 11 months
18	18 month FU	"Long" gutter endoleak	1	Sealed after embolization at 48 months
26	Control angiogram	"Short" gutter endoleak	1	Still present (sac stability at 43 months)
29	32 month FU	"Long" gutter endoleak	2	Programmed for "neck lengthening" by cuff addition and transformation of the Open Chimney into a covered chimney graft
Late period (2015-2017)				
1	1 month FU	"Short" gutter endoleak	2	Present until death secondary to aorto-digestive fistula
6	Control angiogram	"Short" gutter endoleak	1	Present until death from cardiac arrhythmia
7	Control angiogram	"Short" gutter endoleak	1	Still present (sac stability at 11 months)
11	Control angiogram	"Long" gutter endoleak	2	Sealed after embolization at 16 months
12	Control angiogram	"Long" gutter endoleak	2	Sealed after endo-anchoring at 2 months
34	Control angiogram	"Short" gutter endoleak	1	Sealed spontaneously at 3 months

FU = follow-up.

"short" gutter endoleaks : confined to the perigraft channel or those terminating within 10 mm of the most inferior chimney stent and not associated with aneurysm sac perfusion.

"long" gutter endoleaks : extending >10 mm below the most inferior chimney stent and/or extending into the aneurysm sac.

Table 6. Aneurysm-related reinterventions

Characteristic	Total	Early period (2010-2014)	Late period (2015-2017)
Endovascular repair	23	15	8
Endoleaks	10	7	3
Type Ia	4	2 *	2 †
Type Ib	2	1 ‡	1 ‡
Prevention of Type Ib	3	3 §	0
Type III	1	1 **	0
Iliac rupture	1	1	0
Occluded Open chimneys	2	0	2 ††
Open surgery	5	2	3
Iliac limb occlusion	2	2 ‡‡	0
Femoral false-aneurysm	2	0	2
Hemostatic Nephrectomy	1	0	1

* Embolization

† 1 Embolization and 1 Endo-anchoring

‡ Hypogastric embolization and iliac extension

§ 3 procedures/2 patients with aneurysmal degeneration of the common iliac arteries

** Addition of a covered stent between limb modules

†† Unsuccessful

‡‡ 1 thrombectomy + stenting and 1 femoro-femoral bypass

Only the gross values are given since freedom from aneurysm related-reintervention rates were calculated using Kaplan-Meier estimates