Long-term outcomes of chimney endovascular aneurysm repair procedure for complex abdominal aortic pathologies

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ABSTRACT

Objective: The aim of this study was to update our earlier experience and to evaluate long-term outcomes of chimney endovascular aortic repair performed for selected cases with complex abdominal aortic aneurysm.

Methods: A single-center retrospective cohort study was conducted on 51 consecutive patients who underwent chimney endovascular aortic repair procedure, deemed unfit for open surgical repair and fenestrated endovascular aneurysm repair, from October 2009 to November 2019. Kaplan-Meier analyses were used to assess the estimated overall survival, freedom from aneurysm related mortality, freedom from reintervention, freedom from target vessel instability, and freedom from type Ia endoleaks.

Results: Fifty-one patients (mean age, 77.1 ± 7.5 years) with a mean preoperative maximum aneurysm diameter of 74.2 ± 20.1 mm were included. Mean follow-up duration was 48.6 months (range, 0-136 months). Estimated overall survival at 5 and 7 years was 36.3% ± 7.1% and 18.3% ± 6.0%, respectively. Freedom from aneurysm-related mortality was 88.6% ± 4.9% at 7 years. Estimated freedom from type Ia endoleaks at 7 years was 91.8% ± 3.9%. A total of 21 late reinterventions were performed in 17 patients (33%). Most of them were performed to treat type II endoleaks with sac growth (47.6%; n = 10) and type Ib endoleak (23.8%; n = 5). Estimated freedom from reintervention at 7 years was 56.3% ± 7.9%. Estimated freedom from target vessel instability at 7 years was 91.5% ± 4.1%.

Conclusions: The 7-year results of chimney endovascular aortic repair procedures performed in our center confirm the long-term safety and effectiveness of this technique in a series of high-risk patients with large aneurysms. The present study has, to the best of our knowledge, the longest follow-up for patients treated with chimney endovascular aortic repair, and it provides data to the scarce literature on the long-term outcomes of this procedure, showing acceptable to good long-term results. (J Vasc Surg 2024;80:612-20.)

Keywords: Abdominal aortic aneurysms; ChEVAR; Chimney; Chimney grafts; Endovascular aneurysm repair

Endovascular aneurysm repair (EVAR) has become the first choice of treatment for abdominal aortic aneurysms (AAAs) both in elective and urgent/emergent aneurysm repair. Nevertheless, standard EVAR requires selected anatomy to fit the 'instructions for use' of commercially available stent grafts. The main anatomical feature involved in AAAs that implies not meeting the specified requirements is the lack of a suitable infrarenal neck,[1] particularly due to the insufficient proximal neck length in short-neck AAA and in juxtarenal aneurysms (JAAAs). The first-choice treatment for JAAAs is not yet well-defined and is based on patient clinical status and anatomy characteristics.[2] Nowadays, open surgical repair (OSR) with suprarenal aortic cross-clamping and fenestrated EVAR (fEVAR) should be both considered treatments of choice for this aortic pathology.[2] However, in high-risk patients, emergency settings or when fEVAR is not indicated nor available, chimney endovascular aneurysm repair (chEVAR) should be considered.[3]

ChEVAR was first used at the beginning of this century.[4] Although, initially, chimney grafts (CGs) were only adopted in acute cases and as a bailout procedure, more recently, it has become an option for elective selected cases with complex abdominal aortic pathologies in patients unfit for OSR and fEVAR.[2,3] Midterm

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results seem acceptable; however, long-term outcomes for chEVAR are still under discussion due to a lack of data in the literature. The aim of this single-center retrospective cohort study is to update our previously described experience[5] and provide long-term outcomes of this technique.

ARTICLE HIGHLIGHTS

- **Type of Research**: Single-center retrospective cohort study
- **Key Findings**: Chimney endovascular aortic repair, performed in 51 consecutive high-risk patients with complex abdominal aneurysms, resulted in an estimated 7-year freedom from aneurysm-related mortality of 88.6%, an estimated freedom from target vessel instability at 7 years of 91.5%, and an estimated 7-year freedom from type Ia endoleak of 91.8%.
- **Take Home Message**: Chimney endovascular aortic repair showed acceptable to good long-term outcomes in a series of high-risk patients with complex abdominal aortic aneurysms, unfit for open repair and fenestrated/branched endovascular aortic repair.

METHODS

Patient selection. Fifty-one consecutive patients who underwent chEVAR procedure for complex abdominal aortic aneurysm at University Medical Centre Utrecht, from October 2009 to November 2019, were included. An infrarenal aortic neck of <10 mm denied the execution of standard EVAR. All patients were evaluated as unfit for OSR and fEVAR in a multidisciplinary meeting. In urgent clinical settings, no consultation about fEVAR was made. One or more of the following comorbidities were considered reasons to designate a patient as high risk and were criteria for exclusion from OSR: severe chronic obstructive pulmonary disease, congestive heart failure, coronary artery occlusive disease, and hostile abdomen. Anatomic criteria that prohibited the execution of fenestrated or branched EVAR were severe angulation of the aorta at the level of the target vessel, a narrow diameter of the aorta at the level of the target branches, and very diseased or narrow (≤4 mm) target branches.

Preoperative planning based on computed tomographic angiography (CTA) was performed in all cases using a dedicated software (3mensio Vascular 4.3; 3mensio Medical Imaging BV). The number of chimneys required has been determined with the aim of achieving a proximal landing zone length of at least 15 mm.

Standard procedure. ChEVAR procedures were mostly performed under general anesthesia (n = 50). Until June 2013, all procedures (n = 20) were performed in a standard operating room using mobile C-arm (Veradius; Philips Medical Systems); from then on, all chEVAR (n = 31) were performed in a hybrid operating room (Allura FD20; Philips Medical Systems). The standardized chEVAR technique used has already been described step-by-step in our previous study.[5] Patients were treated with dual antiplatelet therapy (clopidogrel 75 mg and aspirin 100 mg daily) for 6 months postoperatively, followed by single antiplatelet therapy indefinitely thereafter.

Surveillance and follow-up. During the postoperative course, CTA and laboratory examinations were performed on all patients before discharge. The subsequent follow-up protocol consisted of physical and laboratory testing after 6 weeks and yearly control CTA scans. Clinical success at latest follow-up was defined based on the analysis of last CTA performed on the patient, findings from the last clinical visit performed in the outpatient clinic, or as reported by the general practitioner.

Analysis. Patients' electronic medical records were analyzed to extract data on medical and surgical history, medications, laboratory results, and intraoperative and postoperative outcomes including complications, deaths, and reinterventions.

Last preoperative, first postoperative, and last performed CTA images were analyzed and described by two different authors (P.V. and L.F.) according to the latest reporting standards.[6]

Last preoperative, last postoperative before discharge, and last available serum creatinine concentrations were noted to define renal function changes. Acute postoperative renal function changes were graded using Risk, Injury, Failure, Loss, and End-stage renal disease (RIFLE) criteria.[7] Long-term renal function deterioration was defined following the latest reporting standard[6] as >30% decrease from baseline in estimated glomerular filtration rate (eGFR). Outcomes were defined according to the reporting standards of the Society of Vascular Surgery[8] and the reporting standards for endovascular aortic repair of aneurysms involving the renal-mesenteric arteries.[6] The operative technical success was defined as the successful deployment of all intended devices with absence of type I or III endoleak at confirmation angiography. Considering that gutter endoleaks may spontaneously resolve within the first 30 days, as reported in the latest Society of Vascular Surgery reporting standards,[6] we also reported the technical success at 30 days, analyzing postoperative CTA performed within 30 days.

This study does not fall under the scope of the Dutch Medical Research Involving Human Subjects Act (WMO). Therefore, it does not require approval from an accredited medical ethics committee in the Netherlands. However, at UMC Utrecht, an independent

quality check has been carried out to ensure compliance with legislation and regulations (23U-0127). Retrospective data analysis was performed according to the Strengthening the Reporting of Observational studies in Epidemiology (STROBE) recommendations for cohort studies.[9]

Endpoints. Primary endpoints included overall and aneurysm-related mortality, freedom from target vessel instability, freedom from reintervention, and freedom from type Ia endoleak (TIaEL). Secondary endpoints considered were clinical success and complications at last follow-up.

Statistics. Statistical analysis was performed using SPSS Statistics version 28.0.1.0 (IBM Corp). Continuous variables are presented as the mean ± standard deviation and categorical variables as frequencies and percentages. Kaplan-Meier analyses were used to assess the estimated overall and freedom from aneurysm-related mortality, freedom from reintervention, freedom from target vessel instability, and freedom from TIaEL. Estimated values were reported only when the standard error (se) did not exceed 10%, according to the latest reporting standard.[6]

RESULTS

Preoperative characteristics. Baseline characteristics are listed in Table I. A total of 51 patients who underwent chEVAR from 2009 through 2019 were included. The mean age of patients at surgery was 77.1 years (±7.5 years), with a mean maximum aneurysm diameter of 74.2 mm (±20.1 mm). The most common indications for surgery were juxta/suprarenal aneurysm (54.9%; n = 28) and TIaEL after regular EVAR (35.3%; n = 18).

Procedural data. Intraoperative characteristics are listed in Table II. Elective surgery was the most performed (84.3%; n = 43), with all remaining cases being symptomatic, whereas no ruptured aneurysms were treated. General anesthesia was used in 98.0% of cases (n = 50). A total of 83 of an intended 83 chimneys were performed (1.63 CGs/patient). Self-expandable covered stents were used in 79.5% (n = 66) of chimneys, self-expandable covered stents reinforced with balloon-expandable stent were used in 8.4% (n = 7), and balloon-expandable covered stents (BECSs) alone were used in 7.2% (n = 6). CGs involved 2 vessels in 54.9% (n = 28) of cases, one vessel in 41.2% (n = 21) and more than two vessels in 3.9% (n = 2). No cases of intraoperative death or conversion to open repair were recorded. Endurant (Medtronic) was the most used aortic endograft (88.2%; n = 45). Mean oversizing was 26.14% (±6.9%) and the mean total used sealing zone length was 23.0 mm (±9.3 mm).

Early outcomes. Details on early outcomes are listed in Table III. Operative technical success was 84.3% (n = 43), whereas technical success at 30 days was 82.4% (n = 42). At completion angiography, TIaELs and type III endoleaks (TIIIELs) were noted in 13.7% (n = 7) and 3.9% (n = 2) of patients, respectively. At the first postoperative CTA, TIaELs resolved spontaneously in four patients, whereas the endoleak persisted in three patients (5.9%); TIIIEL was reported in 5.9% of patients (n = 3), with two of three endoleaks persisting from the completion angiography; type Ib endoleak (TIbEL) occurred in 2.0% of patients (n = 1) and CG occlusion was observed in 3.9% of patients (n = 2). At least one early complication occurred in 33.3% of patients (n = 17). All-cause 30-day mortality was 3.9% (n = 2). The first patient, treated with bilateral renal CGs for symptomatic JAAA, developed acute renal failure due to CGs occlusion, probably caused by cardiac embolisms or low-flow state, and died on postoperative day 18 after refusing further intervention. The second patient died of nosocomial pneumonia on postoperative day 23. CG early occlusion occurred in 3.9% of patients (n = 2). One patient is the first patient described above; the other showed an occlusion of the CG that was deployed in a crossing configuration and protruded almost 2 cm above the proximal bare metal stent (PBMS) of the main device. The patient was discharged with a stable serum creatinine concentration, not requiring dialysis. All 3 patients reported with early TIaEL underwent chEVAR to treat persistent TIaEL after EVAR. They were octogenarians with large aneurysms (>63 mm), numerous comorbidities, and anatomy unsuitable for fEVAR. These TIaELs were observed during angiography at the end of the procedure. However, since they were low-flow gutter TIaELs, we decided not to treat them intraoperatively. One TIaEL resolved spontaneously during follow-up and was probably related to a main graft oversizing of 13%. The other two patients had persistent TIaELs associated with sac growth. The first patient had TIaEL, probably due to insufficient oversizing (17%), and presented a growing symptomatic left hypogastric aneurysm of 97 mm caused by type II endoleak (TIIEL) but decided to refrain from further intervention and died within 3 years from surgery. Cause of death was undetermined because no autopsy was conducted. The second patient had persistent TIaEL after chEVAR, probably due to excessive oversizing (45%), but refused any reintervention. The patient was still asymptomatic at last follow-up (53 months).

Long-term outcomes. Long-term outcomes characteristics are reported in Table III. Mean clinical follow-up duration was 48.6 months (range, 0-136 months), and mean imaging follow-up duration was 40.6 months (range, 0-130 months). No patients were lost to follow-up. The reported all-cause mortality at last follow-up was 78.4% (n = 40), with an estimated overall survival at 5 and 7 years of 36.3% (±7.1%) and 18.3% (±6.0%), respectively (Fig 1, *A*). Estimated freedom from aneurysm-related mortality was 88.6% (±4.9%) at 7 years (Fig 1, *B*). The

Table I. Baseline characteristics

Characteristic	Total cohort
Total no.	51
Age, years	77.1 ± 7.5
Gender, male	43 (84.3)
BMI, kg/m^2	26.0 (5.0)
Smoke	
Current	9 (17.6)
Former	15 (29.4)
No/not reported	27 (52.9)
Hypertension	
None (diastolic pressure usually <90 mmHg)	12 (23.5)
Controlled with 1 drug	12 (23.5)
Controlled with 2 drugs	14 (27.5)
Requires >2 drugs or is uncontrolled	13 (25.5)
Peripheral artery disease	7 (13.7)
Cardiac status	
Asymptomatic, with normal ECG	21 (41.2)
Asymptomatic, but with MI >6 months, occult MI on ECG, or fixed defect on stress test	11 (21.6)
Stable angina, reversible defect on stress test, silent ischemia on Holter, EF 25%-45%, controlled arrhythmia, history of CHF	15 (29.4)
Unstable angina, symptomatic or poorly controlled arrhythmia, poorly compensated or recurrent CHF, EF <25%, MI <6 months	4 (7.8)
Coronary disease	24 (47.1)
Arrhythmias	15 (29.5)
Diabetes mellitus	8 (15.7)
Stroke/TIA	9 (17.6)
Lung status	
Asymptomatic, with normal chest radiograph	35 (68.6)
Asymptomatic or mild dyspnoea on exertion, mild chronic parenchymal changes, function tests 65%-80% of predicted	9 (17.6)
Between 1 and 3	4 (7.8)
Vital capacity 1.85 L, FEV1 <1.2 L or <35%, maximum voluntary ventilation <50%, partial pressure of carbon dioxide >45 mmHg, supplemental oxygen, pulmonary hypertension	3 (5.9)
Cancer	17 (33.3)
CKD	
eGFR ≥90 mL/min/1.73 m^2	4 (7.8)
eGFR 60-89 mL/min/1.73 m^2	18 (35.3)
eGFR 30-59 mL/min/1.73 m^2	24 (47.1)
eGFR 15-29 mL/min/1.73 m^2	3 (5.9)
eGFR <15 mL/min/1.73 m^2	2 (3.9)
Statin	35 (68.6)
Platelet inhibitor	
No	16 (31.4)
Mono antiplatelet	30 (58.8)
Dual antiplatelet	5 (9.8)
Anticoagulation therapy	16 (31.4)
Indication at surgery	
Juxta/suprarenal aneurysm	28 (54.9)
TIaEL after failed EVAR	18 (35.3)
Para-anastomotic aneurysm	5 (9.8)
ASA classification	
1	2 (4.1)
2	17 (34.7)
3	29 (59.2)
4	1 (2.0)
5	0 (0.0)
Maximum aneurysm diameter, mm	74.2 ± 20.1
Proximal sealing zone diameter, mm	27.0 ± 3.3
Proximal sealing zone length, mm	21.8 ± 11.9
Infrarenal diameter, mm	31.5 ± 13.0
Infrarenal sealing length, mm	5.8 ± 6.1

ASA, American Society of Anesthesiologists; *BMI*, body mass index; *CHF*, congestive heart failure; *CKD*, chronic kidney disease; *ECG*, electrocardiogram; *EF*, ejection fraction; *eGFR*, estimated glomerular filtration rate; *EVAR*, endovascular aneurysm repair; *FEV1*, forced expiratory volume in 1 second; *MI*, myocardial infarction; *TIaEL*, type Ia endoleak; *TIA*, transient ischemic attack.
Categorical variables are presented as number (%), and continuous variables are presented as mean (± standard deviation).

most common cause of aneurysm-related death was post-implantation aneurysm rupture in 5.9% (n = 3). Two cases of aneurysm rupture occurred in patients who refused further interventions despite the diagnosis of TIIbEL and TIIIEL with sac expansion. The third patient underwent chEVAR as a last resort for a para-anastomotic aneurysm. Postoperative graft infection with subsequent aortic growth led to sac rupture and death at 5 months after chEVAR. Primary clinical success at last follow-up was 39.2% (n = 20). Late complications occurred in 64.7% of patients (n = 33), and the most common were TIIEL with sac growth in 23.5% (n = 12). Late CG occlusion occurred in 5.9% of patients (n = 3). The first patient showed occlusion of the left renal artery related to an infolding of the proximal part of the CG. The second patient showed occlusion of the right renal artery probably related to the CG deployment below the PBMS of the main graft, which compressed the CG at the proximal end. The third patient showed occlusion of the CG probably due to the small diameter of the target vessels (3.7 mm). Deterioration of renal function was

Table II. Intraoperative characteristics

Characteristic	Total cohort
Timing	
Elective	43 (84.3)
Symptomatic	8 (15.7)
Anesthesia	
General	50 (98.0)
Locoregional	1 (2.0)
Main stent graft type	
Endurant (Medtronic)	45 (88.2)
Excluder (W.L. Gore & Associates)	5 (9.8)
Others	1 (2.0)
Stent graft conformation	
Bifurcation prosthesis	18 (35.3)
Bifurcation prosthesis with proximal extension	9 (17.6)
Uni-iliac prosthesis	4 (7.8)
Proximal cuff only	15 (29.4)
Abdominal tube	5 (9.8)
No. of chimneys	
1	22 (43.1)
2	27 (52.9)
3	1 (2.0)
4	1 (2.0)
Total no. of chimneys intended	83
Total no. chimneys deployed	83
Target vessel in chEVAR procedures	
Right renal artery	38 (45.8)
Left renal artery	35 (42.2)
Superior mesenteric artery	5 (6.0)
Celiac trunk	4 (3.6)
Accessory renal artery	1 (1.2)
Target vessel in chEVAR procedures with one chimney	
Right renal artery	10 (45.5)
Left renal artery	8 (36.4)
Superior mesenteric artery	1 (4.5)
Celiac trunk	2 (9.1)
Accessory renal artery	1 (4.5)
No. of stents deployed per target vessel	
1	15 (18.1)
2	60 (72.3)
3	8 (9.6)
Type of stent used as chimney graft	
Viabahn (W.L. Gore & Associates)	63 (75.9)
Advanta V12 (Atrium Medical Corporation)	6 (7.2)
Viabahn + Advanta V12	5 (6.0)
Viabahn + Everflex (Medtronic)	3 (3.6)
Viabahn + Scuba (Medtronic)	2 (2.4)
Unknown	4 (4.8)
Intraoperative complication	3 (5.9)
Intraoperative unplanned procedures	1 (2.0)
Intraoperative conversions to open surgery	0 (0.0)
Intraoperative death	0 (0.0)
Endoleaks at completion angiography	
Type I	7 (13.7)
Type III	1 (2.0)
Operative technical success	43 (84.3)
Operation duration, minutes	236.8 ± 74.1
Blood loss, mL	670.6 ± 328.9
Contrast agent use, mL	94.1 ± 33.2
Fluoroscopy duration, minutes	54.3 ± 23.1
Proximal oversizing, %	26.14 ± 6.9
Total used seal zone, mm	23.0 ± 9.3

ChEVAR, Chimney endovascular aneurysm repair.
Categorical variables are presented as number (%), and continuous variables are presented as mean ± standard deviation.

found in 13.7% (n = 7) of patients at the last follow-up. In two of them, occlusion of a CG performed in a renal artery was documented. In the other five, no CG complications were reported, and no reintervention on the chimney renal artery was performed. Estimated freedom from target vessel instability at 7 years was 91.5% (±4.1%) (Fig 2). Late TIaELs were noted in 7.8% of patients (n = 4) at last CTA. Two patients with persistent TIaELs were already described in the early outcomes section. The other two patients experienced a late onset of TIaELs related to a total used sealing zone <15 mm. One developed an extensive TIaEL with sac growth but died from SARS-CoV-2 pneumonia. The other showed TIaEL without sac growth and was still alive and asymptomatic at last follow-up (49 months). The estimated freedom from TIaELs at 7 years was 91.8% (±3.9%) (Fig 3, *A*). A total of 21 late reinterventions were performed in 17 patients (33%). Most reinterventions were performed to treat TIIELs with sac growth (47.6%; n = 10) and TIbEL (23.8%; n = 5). Secondary clinical success was 60.8% (n = 31), with an estimated freedom from reintervention at 7 years of 56.3% (±7.9%) (Fig 3, *B*).

DISCUSSION

In the European Society of Vascular Surgery guidelines for aorto-iliac aneurysm management,[2] chEVAR is proposed as an alternative treatment for JAAAs in emergency settings or when fEVAR is not indicated or available. However, long-term outcome data on chEVAR are still scarce. A recently published update from the PERICLES registry[10] has provided the only reported

Table III. Postoperative characteristics

Characteristic	Total cohort
Intensive care duration, days	0 (0-5)
Hospitalization duration, days	4 (1-41)
Early death	2 (3.9)
Patients with at least one early complication	17 (33.3)
Target vessel occlusion	2 (3.9)
TIaEL	3 (5.9)
TIbEL	1 (2.0)
TIIIEL	3 (5.9)
Access site complication	5 (9.8)
Visceral vessel rupture	1 (2.0)
Bowel ischemia	1 (2.0)
Respiratory complication	3 (5.9)
Myocardial infarction	3 (5.9)
Mild acute deterioration of renal function[a]	2 (3.9)
Severe acute deterioration of renal function[b]	2 (3.9)
Early reintervention	4 (7.8)
Repeated EVAR procedure	1 (2.0)
SMA and celiac trunk stenting	1 (2.0)
Access vessel thrombectomy	1 (2.0)
Embolization accessory renal artery	1 (2.0)
Technical success at 30 days	42 (82.4)
Thirty-day primary clinical success	38 (74.5)
Thirty-day secondary clinical success	41 (80.4)
Death at last follow-up	40 (78.4)
Cardiac-related	6 (11.8)
Cancer-related	5 (9.8)
Bowel ischemia	1 (2.0)
Post-implantation aneurysm rupture	3 (5.9)
Postoperative after other surgery	1 (2.0)
CG occlusion	1 (2.0)
Stroke	3 (5.9)
Volvulus	1 (2.0)
Others	14 (27.5)
Unknown	5 (9.8)
Patients with at least one late complication	33 (64.7)
Target vessel occlusion	3 (5.9)
TIaEL	4 (7.8)
TIbEL	2 (3.9)
TIIEL with sac growth	12 (23.5)
TIIIEL	1 (2.0)
Graft limb thrombosis	2 (3.9)
Aorto-enteric fistula	1 (2.0)
Bowel ischemia	2 (3.9)
Graft infection	1 (2.0)
Access vessel stenosis	2 (2.0)
Deterioration of renal function[c]	7 (13.7)
Patients with at least one late reintervention	17 (33.3)
Repeated EVAR procedure	1 (2.0)
Coil or glue embolization	8 (15.7)
Limb extension	5 (9.8)
Stenting celiac trunk	1 (2.0)
Femorofemoral bypass	2 (3.9)
Access vessel correction	2 (3.9)
Open ligation of collaterals	2 (3.9)
Aneurysm shrinkage[d]	14 (27.5)
Aneurysm sac enlargement[d]	10 (19.6)
Primary clinical success	20 (39.2)
Secondary clinical success	31 (60.8)
Latest follow-up sac diameter, mm	75.7 ± 25.9
Mean follow-up, months	48.6 (0-136)

CG, Chimney graft; EVAR, endovascular aneurysm repair; *SMA*, superior mesenteric artery; *TIaEL*, type Ia endoleak; *TIbEL*, type Ib endoleak; *TIIEL*, type II endoleak; *TIIIEL*, type III endoleak.
Continuous variables are reported as median (range), mean ± standard deviation, or mean (range), and categorical variables are reported as number (%).
[a]Mild acute renal function deterioration was defined as 25% to 50% decrease in estimated glomerular filtration rate.
[b]Long-term renal function deterioration was defined as >30% decline in baseline estimated glomerular filtration rate.[6]
[c]Severe acute renal function deterioration was defined as >50% decrease in estimated glomerular filtration rate (Risk, Injury, Failure, Loss, and End-stage renal disease [RIFLE] criteria).[7]
[d]The definition of aneurysm sac enlargement or shrinkage is an increase or a decrease in diameter >5 mm or >5% in volume measurements, respectively.[6]

long-term data on chEVAR technique showing favorable results. In this registry, a subset of the total cohort (n = 244 patients with 1.59 CG/patient) with >30 months of follow-up and a mean follow-up of 46.6 months was segmented for the analysis of specific late outcomes.

In our study, we presented the long-term outcomes as an update of our previous experience[5,11] with the aim of providing further data to the literature. In our population, the mean follow-up was 48.6 months, and, to the best of our knowledge, it is the longest described in the literature. Despite inherent limitations, we found it crucial to compare our findings with the data from the PERICLES registry,[10] as it is the only other study that addresses the long-term outcomes of chEVAR. In our study, the estimated overall survival at 5 years is 36.3%, which is lower than the 66.1% reported in the PERICLES analysis.[10] This difference could be explained by several factors. First, in the PERICLES study group, fEVAR was only available in three of 13 participating centers, which may have contributed to favorable outcomes because they included patients with anatomy suitable for fEVAR, which frequently means less diseased aortic and

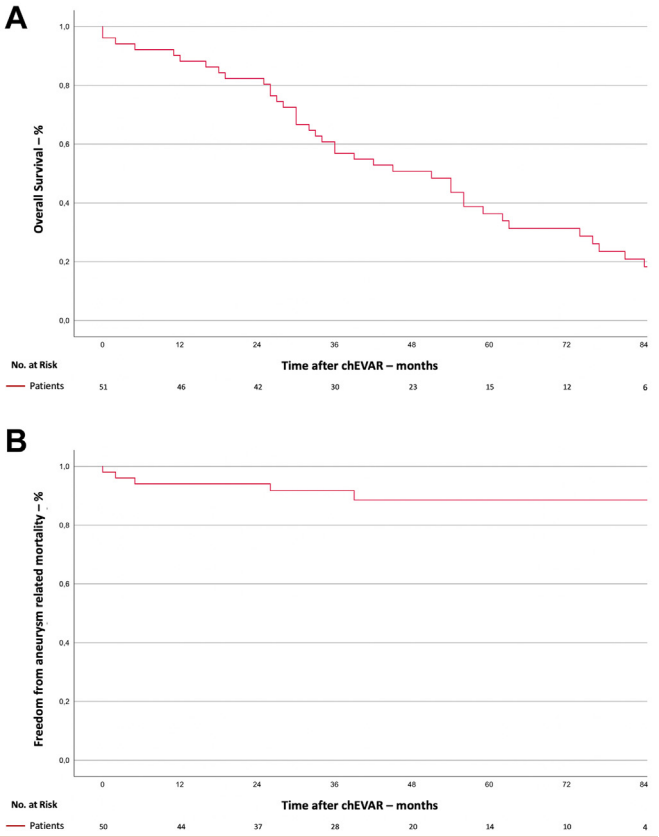

Fig 1. Kaplan-Meier curve showing estimated overall survival **(A)** and estimated freedom from aneurysm-related mortality **(B)**. Estimated values were reported only when the standard error (se) did not exceed 10% according to the latest reporting standard.[6] *ChEVAR*, Chimney endovascular aneurysm repair.

branched vessels. In our center, chEVAR is the last option, performed only in patients with complex aortic anatomy unfit for fEVAR, and when no other alternatives are available. Secondly, the mean maximal preoperative sac diameter was greater than described in the PERICLES registry[10] (74.2 mm vs 65.8 mm). The higher mortality rate for patients with large aneurysms (≥65 mm) undergoing standard EVAR procedures has already been described in literature with a 5-year adjusted survival rate of 55.3%.[12] Furthermore, our patient population had an older mean age at surgery (77.1 years vs 75.2 years) than the PERICLES registry. Considering both factors, which suggest a more fragile population, an estimated overall survival of 36.3% and a freedom from aneurysm-related mortality of 88.6% at 5 years can be considered acceptable to good results. In our population, three patients died of ruptured aneurysm. Two of them refused further reintervention to treat TIbELs and TIIIELs because of their age and fragility, and one developed a stent graft infection. All of them underwent chEVAR to treat large aneurysms (diameter range, 83-155 mm), and no other treatment options were available.

The same considerations apply to the complications and reinterventions. In recent literature,[13] the reported rates of major early complications following FEVAR and OSR are 23.1% and 43.5%, respectively. Therefore, our complication rate of 33.3% can be considered an acceptable result, especially considering that we included both major and minor complications. As is well-known, reinterventions after endovascular aneurysm repair for complex aortic pathology are common. In our population, most reinterventions were performed to treat TIIELs with sac growth and TIbELs, which means they probably would have occurred even after performing other endovascular treatments. The estimated freedom from reintervention at 7 years was 56.3%, and, although the need for reintervention remained high, it is similar to the results described in the literature for fEVAR.[14-20] Any long-term overall reinterventions rate for chEVAR population has not yet been reported.

The estimated 7-year primary freedom from target vessel instability in our population, using mainly self-expandable CGs, was 91.5%. This is consistent with the rate reported by the subgroup analysis in the PERICLES registry[10] and is slightly better than the rates reported in the literature for fEVAR.[14,21,22] In a recent prospective, multi-center, nonrandomized clinical study reported by Oderich et al,[14] the primary renal target patency in fEVAR performed to treat JAAAs, was 82.7% at 5 years. In the single-center retrospective cohort study by Sveinsson et al,[22] which exhibits similar characteristics to our investigation, a primary target vessel patency rate of 89% at 5 years after fEVAR for treating JAAAs is reported. In our population, CG occlusion was recorded only in five patients. In four of them, chEVAR was performed using a mobile C-arm. Three of these CG occlusions were likely related to inaccurate deployment of the CGs, probably due to difficulty in identifying the stent markers during the procedure with the mobile C-arm, resulting in an excessive length of the CGs, a crossing configuration of the CGs, or a proximal CG deployment below the PBMS of the main graft. Furthermore, one of these CGs was also deployed in a target vessel with diameter less than 4 mm. Despite evidence from clinical practice, the comparison between procedures performed in a standard operating room using a mobile C-arm and those performed in a hybrid operating room did not reveal any significant statistical differences regarding primary outcomes, likely due to the small sample size.

To lower the risk of CG occlusions, we suggest avoiding CGs in target vessels with a diameter less than 4 mm,[23] as well as excessive length of the chimneys and unnecessary ballooning of the main graft at the level of the chimneys.

Another major concern about chEVAR remains the long-term freedom from TIaEL. The chimney configuration is prone to TIaEL when gutters between the main device and the CG persist, but results reported in our previous study showed decreases of gutter size over time.[5] Recent

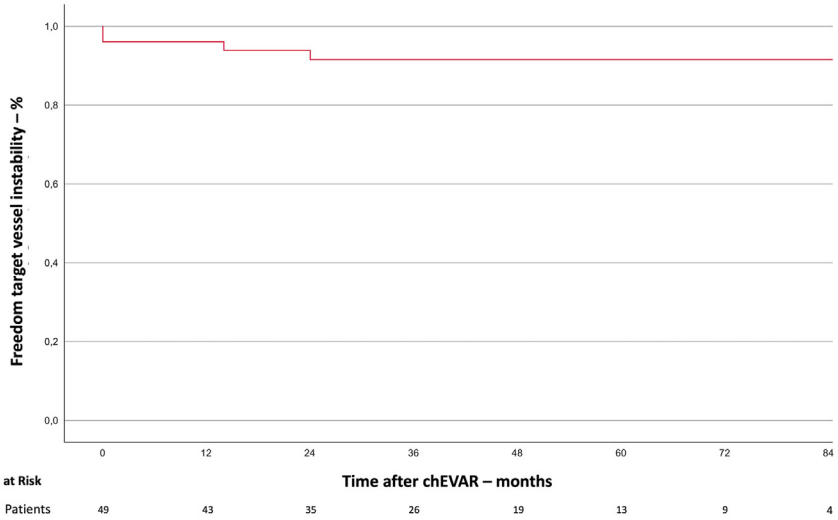

Fig 2. Kaplan-Meier curve showing estimated freedom from target vessel instability. Estimated values were reported only when the standard error (se) did not exceed 10% according to the latest reporting standard.[6] *ChEVAR*, Chimney endovascular aneurysm repair.

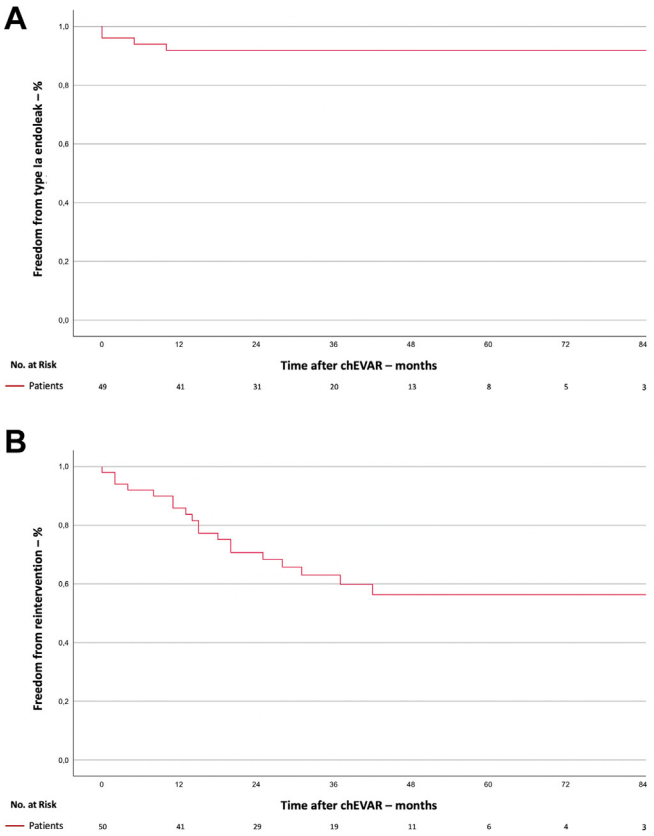

Fig 3. Kaplan-Meier curve showing estimated freedom from type Ia endoleak **(A)** and estimated freedom from reintervention **(B)**. Estimated values were reported only when the standard error (se) did not exceed 10% according to the latest reporting standard.[6] *ChEVAR*, Chimney endovascular aneurysm repair.

data described in the literature about late TIaEL after chEVAR[10] are similar to our results with an estimated freedom from TIaEL at 7 years of 91.8%. In our series, TIaEL was recorded only in four patients at last follow-up. In three of these patients TIaEL was probably related to an aortic main graft oversizing <20% or >40%, and in one patient, TIaEL was likely related to a total used sealing zone length <15 mm. Based on our experience, we recommend using self-expandable covered stents (Viabahn; W.L. Gore & Associates), a 20% to 30% proximal oversizing and a total used sealing zone length ≥15 mm, avoiding the 'crossing configuration' of the CGs to reduce the risk of TIaEL.[5,12] Some authors suggest that gutter-related endoleaks of chEVAR are commonly low-flow, and there is a lack of evidence about causal relationship between TIaELs in chEVAR and aneurysm sac growth.[24] Given these considerations, we suggest treating this complication only in selected patients with sac expansion.

With regard to the best combination of main device and CGs to use in chEVAR procedures, an in vitro study suggested avoiding the Endurant-Viabahn combination due to the significant higher compression of CG showed with Viabahn compared with BECSs, despite higher stent area compression resulted in smaller gutters.[25] However, a more recent in vivo study conducted from the PERICLES group showed no significant evidence of higher risk in CG occlusion with Endurant-Viabahn compared with other device combinations.[26] Based on our results and the above considerations, we assessed that the Endurant-Viabahn combination is a viable option to reduce the gutter areas without any significant evidence of higher risk of CG occlusion.

The strength of our study is that chEVAR was restricted to high-risk patients with large aneurysms who were ineligible for OSR and fEVAR. All procedures were performed by vascular surgeons from the same clinical team, following the same standardized technique,[12] with the deployment of self-expandable covered stents as CGs prior to the main graft, using two stents per target vessel, in most cases, and avoiding kissing balloons after CGs deployment. However, the retrospective nature and the small sample size are the main limitations of our study, making our results vulnerable to bias.

CONCLUSIONS

These single-center 7-year results of chEVAR procedures confirm the long-term safety and effectiveness of this standardized technique in a series of high-risk patients with complex aneurysms, unfit for open repair and fEVAR. The present study has, to the best of our knowledge, the longest follow-up for patients treated with chEVAR, providing new data to the scarce literature on the long-term outcomes of this procedure, showing acceptable to good long-term results.

AUTHOR CONTRIBUTIONS

Conception and design: PV, LF, ST, CH, JH
Analysis and interpretation: PV, LF, JH
Data collection: PF, LF, TB
Writing the article: PV, LF
Critical revision of the article: PV, LF, TB, ST, CH, JH
Final approval of the article: PV, LF, TB, ST, CH, JH
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PV and LF contributed equally to this article and share co-first authorship.

DISCLOSURES

J.A.v.H. is a consultant for Terumo Aortic, Gore Medical, Cook and Philips Medical systems. C.E.V.B.H. is a consultant for Terumo Aortic, Gore Medical, Cook and Philips Medical systems. S.T. is a consultant and speaker for Medtronic Inc, Gore Medical, and Terumo Aortic.

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