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► To cite this version:

Joseph Touma, Caroline Caradu, Raphaëlle Sylvestre, Nicla Settembre, Fabrice Schneider, et al.. Multicentre Experience with the Chimney Technique for Abdominal Aortic Aneurysms in French University Hospitals. *European Journal of Vascular and Endovascular Surgery*, 2020, 59, pp.776 - 784. 10.1016/j.ejvs.2020.01.040 . hal-03490883

HAL Id: hal-03490883

<https://hal.science/hal-03490883v1>

Submitted on 22 Aug 2022

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Multicentre Experience with the Chimney Technique for Abdominal Aortic Aneurysms in French University Hospitals

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Short title: Multicentre Experience with ChEVAR

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Objective: The chimney technique (ChEVAR) allows for extension of the proximal landing zone for endovascular repair of complex aortic aneurysms. The goal of the present study was to assess ChEVAR national outcomes in French university hospital centres.

Methods: All centres were contacted and entered data into a computerised online database on a voluntary basis. Clinical and radiological data were collected on all consecutive ChEVAR patients operated on in 14 centres between 2008 and 2016. Patients were deemed unfit for open repair. Factors associated with early (30 day or in hospital) mortality and type 1 endoleak (Type I EL) were calculated using a multivariate analysis.

Results: In total, 201 patients with 343 target vessels were treated. There were 94 juxtarenal (46.8%), 67 pararenal (33.3%), 10 Crawford type IV thoracoabdominal (5%) aneurysms, and 30 (15.1%) proximal failures of prior repairs. Pre-operative diameter was 66.8 ± 16.7 mm and 28 (13.9%) ChEVAR were performed in emergency, including six (2.9%) ruptures. There were 23 (11.7%) unplanned intra-operative procedures, mainly related to access issues. The rate of early deaths was 11.4% ($n = 23$). Elective mortality rate was 9.8% ($n = 17$). Nine patients (4.5%) presented a stroke. The rate of early proximal Type I EL was 11.9%. Survival was 84.6%, 79.4%, 73.9%, 71.1% at 6, 12, 18, and 24 months, respectively. Primary patency

of chimney stents was 97.4%, 96.7%, 95.2%, and 93.3% at 6, 12, 18, and 24 months, respectively. Performing unplanned intra-operative procedures (OR 3.7, 95% CI 1.3–10.9) was identified as the only independent predictor for postoperative mortality. A ChEVAR for juxtarenal aneurysm was independently associated with less postoperative Type I EL (OR 0.17, 95% CI 0.05–0.58).

Conclusion: In this large national ChEVAR series, early results were concerning. Reasons may lie in heterogeneous practices between centres and ChEVAR use outside of current recommendations regarding oversizing rates, endograft types, and sealing zones. Future research should focus on improvements in pre-operative planning and intra-operative technical aspects.

Keywords: Aneurysm, Aortic, Chimney, Juxtarenal, Multicentre

WHAT THIS PAPER ADDS

In contrast to prior reports regarding the chimney technique for complex abdominal aortic aneurysms, this large national series provides concerning early results with this technique. Performing unplanned intra-operative procedures was identified as the only independent predictor for postoperative mortality. Based on these results, future research should focus on improvements in pre-operative planning and intra-operative technical aspects.

INTRODUCTION

Endovascular aortic repair (EVAR) associated with parallel stents in the visceral arteries, namely the chimney technique (ChEVAR), aims to extend proximally the sealing zone in short or no proximal neck aneurysm configurations. In abdominal aneurysms, ChEVAR applies to juxtarenal (JRA), pararenal (PRA), and Crawford type IV thoracoabdominal (TAA) endovascular repairs. After its initial use as a bailout procedure in cases of inadvertent coverage of renal or visceral arteries during EVAR,¹ ChEVAR gained acceptance as an endovascular alternative in the treatment of complex aneurysms. In contrast to fenestrated endovascular aortic repair (FEVAR), ChEVAR offers the advantages of immediate availability, lower cost, and lower profile for associated aortic devices. Furthermore, ChEVAR can overcome some anatomical contraindications of FEVAR related to aortic angulation, renal or visceral ostia proximity, and target vessel orientation. On the other hand, ChEVAR requires upper access with a risk of embolic stroke in atheromatous aortic arches,

and risks exposure to gutter-related type 1 endoleaks (Type I EL) with a risk of proximal sealing failure.²

Reporting standards are limited for ChEVAR procedures.³ Systematic reviews collecting and evaluating the related data suffer from the same lack of standardisation and present many limiting factors.⁴ However, reported 30 day mortality appears to be low, chimney graft (CG) patency rate is high, and the risk of Type I EL seems acceptable.^{5,6} Several series from France have been published separately, none of which demonstrated such satisfactory outcomes for ChEVAR⁷⁻⁹ and alternate reviews did not support widespread use of ChEVAR's.¹⁰ The present study intends to assess the national outcomes of ChEVAR in a “real-life” setting including all French university hospitals, and to identify potential predictive factors for postoperative mortality and complications.

MATERIALS AND METHODS

Participating centres

All French university hospitals were contacted by e-mail through the AURC (Association pour la Recherche en Chirurgie Vasculaire) and were invited to participate in the study. Participation was voluntary and 14 university centres participated in the study (Table S1). All consecutive cases of abdominal ChEVAR performed in these centres between January 2008 and January 2016 were included, regardless of type of aneurysm and operative context. Patients with thoracic aneurysms, aortic dissections, or chimney endovascular aortic sealing (ChEVAS) cases were not included. ChEVAR combined with homemade FEVAR were excluded. Collected information concerned patients' pre-operative characteristics, indication for ChEVAR, aneurysm type and anatomy, intra-operative details with the type and sizing of the stent grafts, peri-operative events, and follow up related events. Clinical and radiological data were reviewed and analysed locally in each participating centre. The reasons for choosing ChEVAR as a treatment were collected, as well as data regarding aortic stent graft type, oversizing rate, number and type of CGs. The follow up modalities were at each centre's discretion. In all centres, a postoperative CT scan was requested within the first month after the intervention. Duplex-scan examination was used as an alternative imaging method when CT scan was not possible (kidney disease).

Data collection

Data were collected with REDCap (Research Electronic Data Capture) software, originally developed at the Vanderbilt University (USA).¹¹ Access to this software is possible online with any type of operative software and data collection is secure. Because it was a non-interventional retrospective review of anonymous data, Patient Protection Committee Review

(Institutional Review Board) was not necessary. The study complied with the principles of the Declaration of Helsinki.

Definitions

Juxtarenal aneurysms (JRA) were defined as aneurysms extending up to the level of the renal arteries, while pararenal aneurysms (PRA) involved the renal arteries, with or without reaching the origin of the superior mesenteric artery (SMA). Crawford type IV thoraco abdominal aneurysms (TAA) corresponded to aneurysms extending to SMA and celiac artery below the level of the diaphragm.

For chronic renal function alteration, the widely employed chronic kidney disease (CKD) staging system developed by the National Kidney Foundation was chosen.¹² Coronary disease was defined as an abnormal stress test or coronary angiogram, a history of myocardial infarction or coronary artery revascularisation. An ejection fraction under 30% defined heart failure. Chronic obstructive pulmonary disease (COPD) was diagnosed on respiratory function studies or identified in patients under active medication.

Dyslipidaemia was defined as baseline total cholesterol >5 mmol/L. Diabetes was defined as fasting blood glucose levels of >7 mmol/L checked twice and/or the presence of diabetes symptoms (polyuria, polydipsia, weight loss) + random plasma glucose ≥ 2 g/L (11.1 mmol/L) and/or oral glucose tolerance test (OGTT) two hour glucose in venous plasma ≥ 200 mg/dL (≥ 11.1 mmol/L), and/or patient under active medical treatment. Hypertension was defined as the patient taking antihypertensive medication at recruitment or blood pressure >140/90 mmHg at baseline. Cerebrovascular disease was defined as a history of stroke, transient ischaemic attack, or carotid intervention.

The context of emergency was defined by tender or ruptured aneurysms. Technical success was defined as a successfully completed procedure with >15 mm proximal sealing in a disease-free aorta, patent target vessels, and no type I or III endoleak. Clinical success during follow up was defined by the stabilisation or shrinkage of aneurysmal sac.

High-volume centres were defined as participating centres providing >10 patients whereas low-volume centres provided data on ≤ 10 patients, which was entered in the registry.

Statistical analysis

Descriptive analysis

Results for qualitative covariates were expressed as absolute numbers and percentages. Quantitative covariates were expressed as mean \pm standard deviation (SD) when normally distributed, and otherwise as median and range. Group comparison was performed using Student *t* test, Kruskal–Wallis non-parametric tests, Pearson’s chi-square, or Fischer’s exact

tests when appropriate. Comparison of pre- and postoperative aneurysm diameter was compared using a paired *t* test. The prognostic significance of potential variables was first determined by means of univariate logistic regression. All variables yielding *p* values under 0.05 were then integrated into a multivariate analysis to adjust for possible confounders through an ascending stepwise method. The learning curve effect was evaluated by examining early mortality and postoperative Type I EL occurrence in the first five ChEVAR cases group, the first 10 ChEVAR cases group, and the first 20 ChEVAR cases group in centres with >20 patients experience and comparing these subgroups with the rest of each centre's cohort.

Survival analysis

The primary endpoint was the survival rate. The secondary endpoints were primary chimney patency. Cumulative events rates were determined using the Kaplan–Meier method. Survival curves show the subjects at risk of death at all time intervals. Statistical significance was assumed at *p* < 0.05. All reported *p* values were two-sided. All statistical analyses were performed with SAS 9.4 (SAS Institute Inc, Cary, NC, USA).

RESULTS

Study population

During the study period, 201 patients underwent complex abdominal aneurysm endovascular repair with the use of ChEVAR in the participating centres. The age was 75.8±8.2 years. There was a majority of men (*n* = 175, 87.1%). Patients' pre-operative characteristics and the treated aneurysm type are listed in Table 1. ChEVAR was performed as an emergency procedure in 28 (13.9%) procedures, including six (2.9%) ruptures. The treated aneurysms were mostly JRA (*n* = 94, 46.8%) and PRA (*n* = 67, 33.3%). The remaining indications were type 4 TAA (*n* = 10, 5%) and proximal failures of prior repairs (*n* = 30, 15.1%; including Type I EL after EVAR and proximal aneurysms or pseudo-aneurysms after infrarenal open repair). The pre-operative aneurysm diameter was 66.8±16.7 mm. The proximal neck diameter and neck length were 25.3±4.1 and 6.4±4.1 mm, respectively. In all cases, the patients were estimated unfit for open repair after pre-operative assessment. ChEVAR was chosen as a first-line endovascular option in 150 (74.6%) patients, and as a secondary option in the other cases, where fenestrated stent grafts were contraindicated by the manufacturer, or the manufacture delay considered incompatible with the clinical status of the patient.

Intra-operative details

Percutaneous femoral access was used in 22 (11.2%) patients. Bifurcated stent grafts were used in 174 (83.8%) patients, and tubular thoracic and aorto-uni-iliac components were implanted in the remaining 27 (16.2%) patients. Stent grafts with suprarenal fixation were

predominant ($n = 154$, 76.6%). The chosen stent grafts are listed in Table 2. The mean proximal diameter of the aortic stent graft was 31 ± 4.4 mm. The mean oversizing at the level of the proximal neck was $22.6 \pm 13.9\%$. In 43 (21.4%) patients, the oversizing was $\geq 30\%$. In all, 343 target aortic branch vessels were revascularised (270 renal arteries, 59 SMA, 12 celiac arteries, and two polar renal arteries). Single-chimney procedures were performed in 99 (49.2%) cases. The global graft configuration, number and type of chimneys and the eventual use of bare-metal stents for “endolining” are detailed in Table 2. The mean operative time was 210 ± 94 min. The mean fluoroscopy time was 2699 ± 1893 sec and the mean volume of contrast medium was 126 ± 72 mL.

Intra-operative complications

Two patients died intra-operatively. One had a ruptured aneurysm and died before complete aneurysm exclusion. The other died from an iliac rupture during the procedure, in spite of balloon inflation inside the common iliac artery and covered stent deployment. Nineteen target vessels in 14 (7.8%) patients (11 renal arteries, two SMA, one other) presented acute intra-operative thrombosis. Unexpected additional procedures had to be performed in 23 (11.7%) patients. Details of complementary procedures are provided in Table 3. Major endoleaks (type Ia, Ib, and III) were observed in 24 (11.9%) patients on completion angiography, including 18 (8.9%) type Ia endoleaks.

Postoperative events

The 30 day mortality was 11.4% (23/201 patients), including the two intra-operative deaths. Causes of early death are displayed in Table 4. Among the 28 patients who had urgent chEVAR for ruptured or tender aneurysms, the 30 day mortality was 21.4% (6/28), whereas it was 9.8% (17/173) for elective repairs. Major postoperative complications were noted in 61 patients (30.3%), of which 30 (14.9%) led to early reinterventions. In particular, two patients underwent renal artery thrombolysis, and two others ilio-mesenteric bypass for acute SMA occlusion. Early reinterventions are displayed in Table 4. Twenty-two patients (10.9%) developed acute kidney injury, including four (1.9%) who remained under definitive dialysis. Nine patients (4.5%) developed an acute embolic stroke.

Follow up

With a follow up of 14.7 ± 18 months, mortality was 23.3% (47/201). Seven deaths were aortic-related: three secondary ruptures, two bowel ischaemia from CG occlusion, one stent graft infection, and one hepatic artery pseudo-aneurysm rupture. Seventeen (9.5%) patients required a reintervention, all related to the stent grafts. A Kaplan–Meier survival curve for

overall survival is presented in Fig. 1. The estimated patient survival was 84.6%, 79.4%, 73.9%, and 71.1% at 6, 12, 18, and 24 months, respectively.

Proximal Type 1 EL was observed in 24 patients (11.9%) on the first postoperative imaging (CT scan with injection in all but 22 patients who had duplex-scan examination). Early postoperative endoleak distribution is presented in Table 4. Follow up imaging detected that aneurysm diameter decreased to 60.7 ± 18 mm with an individual sac regression of 5 ± 8.6 mm ($p < .0001$ compared with pre-operative diameter). The postoperative length of the new sealing zone was 17.0 ± 4.9 mm. Eighteen (10.1%) late type Ia endoleaks were noted. Ten type Ia endoleaks were already present postoperatively and eight occurred during follow up. Nine patients required late reinterventions (gutter embolisation [$n = 7$], thoracic extension [$n = 1$], endostaples [$n = 1$]), two of whom presented secondary aneurysm rupture during follow up. A Kaplan–Meier curve for primary graft patency is presented in Fig. 2. Primary patency was estimated as 97.4%, 96.7%, 95.2%, and 93.3% at 6, 12, 18, and 24 months, respectively.

Predictors for early and late adverse events

Early mortality

The univariate analysis found three variables associated with 30 day mortality: age > 80 years (OR 3.3, 95% CI 1.3–8.1), unplanned associated procedures (OR 4.3, 95% CI 1.5–12), and number of CGs ≥ 2 (OR 2.5, 95% CI 1.1–6.4). In multivariate analysis, performing unplanned associated procedures (OR 3.7, 95% CI 1.3–10.9) was the only independent predictive factor for postoperative mortality.

Postoperative type Ia endoleak

The univariate analysis revealed two variables associated with proximal Type I EL on the first postoperative imaging: number of CG ≥ 2 (OR 3.4, 95% CI 1.3–8.9) as predictive factor and JRA repair (OR 0.14, 95% CI 0.04–0.5) as preventive factor. The preventive role of JRA was confirmed in multivariate analysis (OR 0.17, 95% CI 0.05–0.58).

Influence of learning curve and cohort volume

The postoperative mortality rate was not significantly different whether patients belonged to the first five cases (6.7%), 10 cases (6.7%), or 20 cases (7.5%) or to the rest of the centre's cohort (14.6%, 12.5%, and 9.7%; $p = .71, .21, \text{ and } .59$, respectively). Type I EL occurrence in early experience cases was also not different to later performed procedures.

Influence of high-volume vs. low-volume participating centres

The postoperative mortality rate was not significantly different whether patients were operated on in high-volume (≥ 10 patients) centres or in low-volume (< 10 patients) centres (12.2% vs. 5.5%; $p = .15$).

DISCUSSION

This national study reports a large experience with ChEVAR in complex abdominal aortic aneurysms from 14 French university hospitals. It highlights concerning early outcomes with this technique. Pre-operative and intra-operative factors associated with early mortality and Type I EL were identified. However, despite concerning early results, primary patency rates appeared acceptable during the reported follow up.

Previous multicentre ChEVAR registries, such as PERICLES⁵ and PROTAGORAS,¹³ demonstrated much better early outcomes than the present study. The present study population had characteristics (comorbidities and anatomies) in the range of these previous reports, especially regarding pre-operative CKD rates and ASA scores, although the rate of active smoking (61.1%, Table 1) was higher in the present study. Of note, active smoking has been reported as a factor associated with early adverse events after EVAR.¹⁴ The present analyses could not determine any effect related to the learning curve or to the operative volume. One reason may be the concurrence of FEVAR in the study country during the study period with a selection of the less diseased patients for FEVAR to the detriment of ChEVAR. Another explanation could be a higher proportion of complex anatomies in the present series, along with a higher frequency of suprarenal configurations (only 46.8% JRA vs. 69% in PERICLES). Finally, the level of expertise of the participating centres might play a role in the observed outcomes, incriminating technical errors, even though the majority of patients were treated at high-volume institutions.

Besides lower mortality and complication rates, the rate of persistent intra-operative Type I EL was also lower in previous large ChEVAR registries (3% for PERICLES vs. 8.9% in the present series). Type I EL observed at the first postoperative imaging was also high in this experience, reaching 11.9%. The number of CGs per patient was in the same range (1.7 in both reports). As stated above, the main difference lies in the rate of JRA (69% in PERICLES vs. 46.8% in the present series). This is confirmed by multivariate analysis, which revealed that ChEVAR for JRA was independently associated with less early Type I EL. This may explain the higher incidence of Type I EL in the present report. ChEVAR would therefore not be the technique of choice to exclude more extended aneurysms. In a study by Scali *et al.*¹⁵ from the PERICLES group, use of multiple chimney stent combinations during the same repair was not significantly associated with type IA endoleak, but with stent occlusion (HR, 1.8 for each additional stent; 95% CI 1.2–2.9; $p = .01$).

Technical aspects could further explain divergent results between ChEVAR studies. First, the stent graft material and type of associated CGs have been evaluated in the above-

cited study.¹⁵ The best combination regarding survival is the polyester/nitinol stent graft used with balloon-expandable covered stents (BECS), especially when compared with polytetrafluoroethylene/nitinol devices. However, polyester/stainless steel devices used with BECS did not significantly differ in terms of postoperative mortality from polyester/nitinol stent grafts (OR 2.1; 95% CI 0.7–6.6; $p = .18$) but were associated with lower one and three year survival rates ($93\pm 3\%$ and $83\pm 7\%$; vs. $97\pm 1\%$ and $92\pm 3\%$ for polyester/nitinol stent graft). In the present report, there was a majority of polyester/stainless steel devices (57.1%), unlike the large PERICLES cohort where polyester/nitinol stent grafts were mainly used. Second, the present study reports a mean oversizing rate of $22.6\pm 13.9\%$. In the PROTAGORAS study,¹³ the grafts were, similarly, oversized between 20% and 30%. It is now recommended to obtain $>25\%$ proximal oversizing to reduce gutter space.¹⁶ Moreover, 30% oversizing is advised in *in vitro* studies to obtain optimal endograft/stent apposition.¹⁷ Third, the length of the postoperative sealing zone is not consensual. The PERICLES registry reports a theoretical neck/seal length of 21.1 ± 12.7 mm and advises 20 mm in general, while the newly created sealing zone in the present study measured 17.0 ± 4.9 mm. The importance of a longer obtained sealing zone has been highlighted through published FEVAR experience. With the increasing use of triple and quadruple fenestrated grafts, the rate of type I EL has significantly dropped, without increasing peri-operative mortality or morbidity.^{18–20}

Imaging data of ChEVAR studies must be addressed with caution in the absence of independent and external review of the data by a core lab in all the existing publications, including the present study. This is in contrast with some previous FEVAR studies.²¹ In the PERICLES registry, only two (0.4%) Type I EL persisted and three (0.6%) others appeared during follow up. In the authors' experience, 10 (5%) Type I EL persisted while eight (4%) appeared *de novo*. A systematic review published in 2015³ reported a 30 day rate of 13% of early Type I EL (range 0–33%) in abdominal ChEVAR. Many were reported to seal spontaneously, but two out of 63 Type I EL induced fatal secondary aneurysm rupture, as observed in the present report. The natural history of gutter-related Type I EL has been described in a monocentric study²² of 60 patients undergoing ChEVAR for complex aneurysms. The Type I EL rate reached 30% on early postoperative imaging studies. Follow up imaging revealed spontaneous resolution of these gutter endoleaks in 44.3%, 65.2%, and 88.4% of patients at 6, 12, and 18 months post-procedure, respectively, suggesting that the natural history of these specific Type I EL might be more benign than originally expected. Of note, Lachat *et al.* advocated that low-flow type I EL after ChEVAR would benefit from simple surveillance.²³

Another vulnerable point of ChEVAR is the mandatory upper limb access, with subsequent neurological morbidity. Postoperative strokes related to the procedure are not infrequent,⁶ although no ChEVAR study reported a systematic postoperative examination by a neurologist. The stroke rate in the present study was 4.5%. Stroke rate is reported by PERICLES authors in a subgroup of 425 patients to be as low as 1.9%.²⁴ Bilateral upper extremity access as in case of multiple CG placements was an independent risk factor for major adverse cardiac and cerebrovascular events. Thus, the higher stroke rate observed in the present study might be explained by the higher proportion of suprarenal configurations (53.3% vs. 31%) compared with juxtarenal anatomies where only one upper access is usually performed. Methods to approach visceral arteries from the femoral arteries to get a chimney configuration might be beneficial in patients at risk.²⁵

A positive conclusion of the present study is the satisfactory patency of the CGs. These high rates of primary patency were also reported in most ChEVAR series, uniformly exceeding 90% at two years.³⁻⁷ This may be related to the usual helical configuration of chimney stents, similar to the side-branches of branched stent grafts, and stabilised by the main aortic stent graft.⁶ In fact, ChEVAR results appear satisfactory once the postoperative period has elapsed, although the mean follow up remains limited in the present series. This highlights the need for focusing ChEVAR improvements in pre-operative planning and intra-operative technical aspects.

In the FEVAR literature, experienced teams have also widened inclusions to standard-risk patients with the advantage of an acquired technique without learning curve effect, availability of modern hybrid suites, and important volume of patients. Expectedly, the 30 day mortality rate was 0.7% and the estimated survival at one and three years was 94% and 85%, respectively.²⁶ On this basis, comparison with open repair for standard-risk patients becomes justified but only possible through retrospective data and delicately matched groups. A literature review of open surgery showed a significantly higher mortality of 3.4% and a new onset of dialysis of 3.9%.²⁷ Propensity-matched comparisons of fenestrated endovascular aneurysm repair and open surgical repair of pararenal and paravisceral aortic aneurysms have shown on one hand no difference in terms of 30 day mortality, dialysis, or organ-specific postoperative complications,²⁸ and, on the other hand, four years earlier in a two-centre study, a much higher mortality for FEVAR (9.5% vs. 2%).²⁹

There are several limitations to the present retrospective study. First, the collected data are self-reported, with no independent core lab intervention. All major reports such as the PERICLES⁵ and PROTAGORAS¹³ registries suffer the same lack of independent assessment

and collection of the clinical and imaging data. In this regard, the ENCHANT Trial³⁰ has been conducted in Europe since October 2017 to assess the clinical outcomes, safety, and performance of the chimney technique when used in JRA (>2 mm neck). Of note, this study is industry-sponsored. Second, the present study revealed heterogeneous practice among the included centres, in the absence of specific guidelines during the study period. Different types of stent grafts and stents were used, as detailed in Table 2. Although the general aspects of the parallel stent procedures were applied, the lack of standardisation of the technique and its indications, as well as the employed grafts and stents, might impede the results' specificity. Centralisation effect and different technical protocols might have an important role in explaining divergent results. Moreover, some teams provided low numbers of patients, without, however, plausible effect on the global outcomes because no significant difference in early outcomes was observed in these low-volume centres. Finally, analysis of the learning curve was performed by centre, not by operator. Nonetheless, this national overview provides a wide photographic recording of the real-world experience in the vascular and endovascular surgery community.

Conclusion

In this large national ChEVAR series, early results were concerning. The study design based on anonymous collection of retrospective data among multiple university centres allows reflection of the real-life experience among practitioners treating complex abdominal aortic aneurysms. The results contrast with the low mortality and morbidity rates that have been published. Reasons may lie in heterogeneous practices between centres and ChEVAR use outside of current recommendations regarding oversizing rates, endograft types, and sealing zones. However, none of the existing information originates from independently controlled data collections. Based on these results, future research regarding ChEVAR should focus on improvements in pre-operative planning and intra-operative technical aspects.

CONFLICT OF INTEREST

Raphael Coscas has been consultant for Medtronic Inc., Gore Inc., Spectranetics Inc., and Bard Inc. and received research grants from Gore Inc. and Spectranetics Inc. Jean-Marc Alsac has been consultant for Medtronic Inc. and Endologix Inc. Other authors do not disclose any conflict of interest.

FUNDING

None.

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Figure 1. Cumulative Kaplan–Meier estimate of patients’ survival following the chimney endovascular aortic repair (ChEVAR) performed in French university centres in 2008–2016.

Figure 2. Cumulative Kaplan–Meier estimate of primary patency of chimney stents following chimney endovascular aortic repair (ChEVAR) performed in French university centres in 2008–2016.

Table 1. Pre-operative characteristics of patients and anatomies of aneurysms treated with chimney endovascular aortic repair (ChEVAR) in French university centres in 2008–2016

Patient characteristics	Patients or aneurysms (<i>n</i> =201)
Age – y	75.8±8.2
Male gender	175 (87.1)
Cardiac insufficiency*	28 (13.9)
Coronary artery disease	86 (42.8)
COPD	47 (23.4)
Oxygen dependence	7 (3.5)
Diabetes	27 (13.4)
Pre-operative CKD	63 (31.3)
Dyslipidaemia	107 (53.2)
Active smoking	120 (60.9)
Hypertension	155 (77.1)
Previous aortic surgery	45 (22.4)
Previous carotid surgery	11 (5.5)
Previous peripheral arterial surgery	34 (16.9)
ASA score	
1	0 (0)
2	46 (22.9)
3	126 (62.7)
4	29 (14.4)
Active cancer	12 (6.1)
BMI – kg/m ²	26.9±4.7
Renal clearance – mL/min	70.4±26.9
Aneurysm anatomies	
<i>Aneurysm type</i>	
<i>Juxtarenal</i>	94 (46.8)
<i>Pararenal</i>	67 (33.3)
<i>TAA4</i>	10 (5.0)
<i>Others</i>	30 (14.9)
Pre-operative AAA diameter – mm	66.8±16.7
Proximal neck length – mm	6.4±4.1

Data are presented as *n* (%) or mean ± standard deviation (SD). AAA = abdominal aortic aneurysm; ASA = American Society of Anesthesiologists; BMI = body mass index; CKD = chronic kidney disease; COPD = chronic obstructive pulmonary disease; TAA = thoraco-abdominal aneurysm.

*Cardiac insufficiency = ejection fraction under 30%.

Table 2. Characteristics of chimney endovascular aortic repairs (ChEVAR) performed in French university centres in 2008–2016

Characteristics of ChEVAR	ChEVAR procedures (<i>n</i> = 201)
Implanted stent grafts	

<i>Zenith (Cook)</i>	113 (56.2)
<i>Endurant (Medtronic)</i>	39 (19.4)
<i>C3 (Gore)</i>	35 (17.4)
<i>AFX (Endologix)</i>	5 (2.5)
<i>Others</i>	9 (4.5)
Stent graft proximal diameter – mm	31±4.4
Mean oversizing – %	22.6±13.9
Chimney stents localisations	
<i>Renal artery</i>	270 (78.7)
<i>Accessory renal artery</i>	2 (1)
<i>Superior mesenteric artery</i>	59 (17.2)
<i>Celiac trunk</i>	12 (3.5)
Number of chimney(s) per case	
<i>1</i>	99 (49.2)
<i>2</i>	67 (33.3)
<i>3</i>	32 (15.5)
<i>4</i>	3 (1.4)
Type of chimney stent (N=343)	
<i>Covered stents</i>	234 (68.2)
<i>Bare metal stents</i>	109 (31.8)
<i>Endolining with a second bare metal stent</i>	181 (52.7)

Data are presented as *n* (%) or mean ± standard deviation (SD).

Table 3. Additional intra-operative procedures during chimney endovascular aortic repairs (ChEVAR) performed in French university centres in 2008–2016

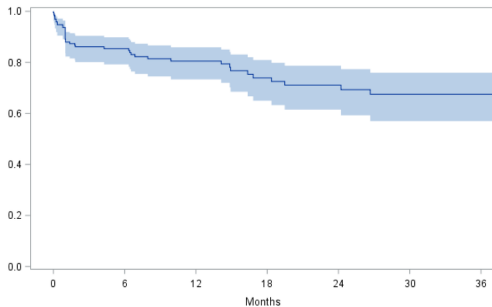
Additional procedures	Patients or aneurysms (<i>n</i> =201) <i>n</i> (%)
Planned procedures	34 (17.2)
<i>Internal iliac artery embolisation</i>	8(3.9)
<i>Femoral endarterectomy</i>	8 (3.9)
<i>Femoro-femoral crossover bypass</i>	6 (3)
<i>Iliac artery angioplasty</i>	6 (3)
<i>Thoracic stent graft implantation</i>	3 (1.5)
<i>Accessory renal artery embolisation</i>	3 (1.5)
Unplanned procedures	23 (11.7)
<i>Access-related procedures (iliac/femoral repair)</i>	11 (5.4)
<i>Additional rescue-chimney grafts</i>	4 (2)
<i>Femoro-popliteal thrombectomy</i>	3 (1.5)
<i>Target artery revascularisation (intra-operative thrombosis)</i>	2 (1)
<i>Aneurysm sac coil embolisation</i>	1 (0.5)
<i>Gutter coil embolisation</i>	1 (0.5)
<i>Renal artery branch embolisation</i>	1 (0.5)

Table 4. Early postoperative reinterventions and endoleak distribution after chimney endovascular aortic repairs (ChEVAR) performed in French university centres in 2008–2016

Early postoperative adverse events	Patients, <i>n</i> (%)
Early mortality	23 (11.4)
<i>Mesenteric/colonic ischaemia</i>	10 (5)
<i>Haemorrhage (iliac rupture, retroperitoneal bleeding)</i>	4 (2)
<i>Stroke</i>	3 (2)
<i>Septic shock</i>	2 (1)
<i>Multiorgan embolic infarcts</i>	2 (1)
<i>Acute respiratory distress syndrome</i>	2 (1)
Early reinterventions	30 (14.9)
<i>Access site haematoma evacuation</i>	5 (2.4)
<i>Bowel resection</i>	5 (2.4)
<i>Iliac or renal relining stents</i>	4 (2)
<i>Iliac/femoral desobstruction</i>	4 (2)
<i>Internal iliac artery embolisation and/or iliac graft extension</i>	4 (2)
<i>Renal stent desobstruction/thrombolysis</i>	2 (1)
<i>Ilio-mesenteric bypass for SMA stent occlusion</i>	2 (1)
<i>Embolisation for arterial perforation</i>	2 (1)
<i>Proximal endostapling</i>	1 (0.5)
<i>Nephrectomy to achieve haemostasis</i>	1 (0.5)
Early endoleak distribution	66 (32.8)
<i>Proximal type 1</i>	24 (11.9)
<i>Distal type 1</i>	2 (1)
<i>Type 2</i>	36 (17.9)
<i>Type 3</i>	3 (1.5)
<i>Type 4</i>	1 (0.5)

Endoleaks correspond to those seen on the one month postoperative imaging. SMA = superior mesenteric artery.

SURVIVAL PROBABILITY



95% Confidence limits

At risk

201

112

84

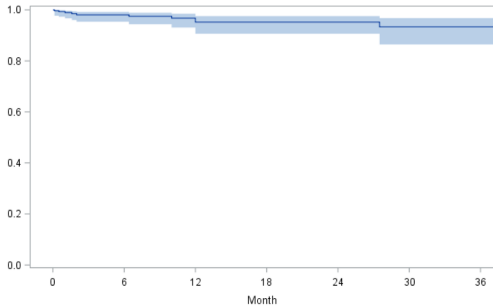
53

42

32

27

PRIMARY PATENCY



95% Confidence limits

Chimney's at risk

343

172

128

78

60

45

39