Meta-Analysis of Chimney vs Fenestrated Endovascular Aneurysm Repair for Complex Aortic Aneurysms

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ABSTRACT: Objective: Increasing experience with fenestrated endovascular aortic repair (FEVAR) of complex aortic aneurysms has shown excellent short- to long-term results, even in high-risk patients. However, anatomical constrains, high price, and lengthy manufacturing time restrict their use to elective patients in specialized centers. Off-the-shelf availability of chimney EVAR (CHEVAR) offers a new alternative, but uncertainties remain over long-term target vessels patency and risk of type Ia endoleak (EL). Our objective was to review the literature reporting comparative results between FEVAR and CHEVAR of complex aortic aneurysms. Methods: A systematic PubMed, EMBASE, CENTRAL, and Ovid search was performed between January 2005 and September 2016. Inclusion criteria were original comparative articles reporting more than 5 patients with complex aneurysms treated by FEVAR or CHEVAR with a minimum 12-month follow-up. Results: Five comparative studies were selected. A total of 126 patients were included in the CHEVAR group (174 target vessels) and 227 in the FEVAR group (510 target vessels). Patients were significantly older in the CHEVAR group (75.8±1.9 vs 72.6±1.5 in the FEVAR group; \(P=0.02\)) and 30 were symptomatic (23.8%, including 4 ruptured aneurysms [3.2%]). There were significantly fewer reconstructed vessels per patient treated by CHEVAR (1.4±0.1 vs 2.3±0.5; \(P=0.004\)). Technical success rate was 92.9% after CHEVAR vs 91.2% after FEVAR (odds ratio [OR]=1.19; 95% confidence interval [CI]: 0.40, 3.55). The 30-day mortality rate was 4.8% after CHEVAR vs 4.4% after FEVAR (OR=0.64; 95% CI: 0.23, 1.76). The 12-month overall target vessels patency rate was 95.9% after CHEVAR vs 97.8% after FEVAR (OR=0.57; 95% CI: 0.17, 1.90). The 12-month rates of type I EL (3.7% vs 1.7%; OR=0.32; 95% CI: 0.08, 1.32), type II EL (6.3% vs 10.1%; OR=1.26; 95% CI: 0.55, 2.89) and type III EL (0.0% vs 0.9%; OR=1.27; 95% CI: 0.13, 12.78) did not differ significantly between both techniques; neither did the rates of secondary interventions (10.0% vs 13.6%; OR=1.23; 95% CI: 0.53, 2.88), overall mortality (9.6% vs 10.5%; OR=0.77; 95% CI: 0.31, 1.87) and aneurysm-related mortality (4.8% vs 4.4%; OR=0.64; 95% CI: 0.23, 1.76). Conclusion: Both CHEVAR and FEVAR are safe and effective in treating complex aortic aneurysms, with numerous advantages and limitations depending on the anatomy and clinical presentation of the patient. Both should remain in the armamentarium of physicians treating complex aortic aneurysms.

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Elective endovascular aneurysm repair (EVAR) is associated with lower rates of perioperative morbidity and mortality, shorter length of hospital stay, and comparable reduction of aneurysm-related mortality compared with elective open surgical repair (OSR). Therefore, treatment has been offered to older patients with more comorbidities, deemed unsuitable for OSR. However, aortic neck anatomic criteria meet the instructions for use (IFUs) of commercial endografts in only 40% of patients. Proximal neck adequacy and seal zones are now identified as key predictors of long-term success, and although newer endografts allow treatment of shorter infrarenal necks (up to 10 mm), a substantial proportion of patients require EVAR devices that involve aortic branches. At first, hybrid techniques emerged, combining EVAR with visceral debranching, leading to substantial morbidity and mortality. New methods were developed to allow an exclusively endovascular approach and have evolved since the early experience of fenestrated EVAR (FEVAR). Fenestrated EVAR helps extend the proximal sealing zone using fenestrations and scallops to provide perfusion to the visceral vessels and showed excellent device-related mid-term results even in high-risk patients, with a possible decrease in perioperative mortality compared to OSR. Recently published long-term results confirmed the safety and effectiveness of FEVAR, and a shift has occurred toward complex aortic devices, which are used now in the majority of primary and reoperative aortic aneurysms or dissection repairs in most large centers. However, engineering of fenestrated endografts with European Conformity (CE) marking and US Food and Drug Administration (FDA) approval is limited by anatomical constraints, such as acute aortic neck angulation (>45°), multiple renal arteries, or close proximity of visceral vessels’ ostias. Moreover, these grafts are expensive and require lengthy manufacturing time, which restricts their use to elective patients in specialized centers.

Greenberg et al were the first to describe the use of parallel stent grafts (Figure 1B) as a bailout strategy to keep patent an artery accidentally covered by the aortic graft. Eventually, chimney EVAR (CHEVAR) offered a new alternative for emergent treatment of complex aneurysms, as its main advantage is its off-the-shelf availability. However, uncertainties remain over the long-term patency of reconstructed vessels and the risk of type Ia endoleak (EL) through the “gutters” created between the aorta, the aortic graft, and the visceral stent. Our objective was to review the literature reporting comparative results between FEVAR and CHEVAR of complex aortic aneurysms.
METHODS

Search Strategy

A systematic PubMed, EMBASE, CENTRAL, and Ovid search was performed, according to the PRISMA statement, using the following key words alone and in combination: “aortic aneurysm,” “chimney,” “snorkel,” and “fenestrated,” restricted to articles published in English between January 2005 and September 2016. The quality of the studies was determined using the Cochrane collaboration’s tool for assessing risk of bias (Figure 2).
**Figure 3. Forest plot of comparison between CHEVAR vs FEVAR studies.** Perioperative (<30 days) mortality rates (A). Target vessels occlusions (B). Type I endoleak rates (C). Secondary interventions’ rates (D). Overall mortality rates (E). Aneurysm-related mortality rates (F).
Article Selection

Inclusion criteria were original comparative articles reporting more than 5 patients with complex aneurysms treated by FEVAR or CHEVAR, in which basic patients’ characteristics, clinical outcomes, graft patency, device-related complications, technical success, and mortality were stated with a minimum 12-month follow-up. Studies reporting patients treated with a hybrid procedure and multibranched stent grafts and review articles were excluded. Sealing zones were classified according to the Society for Vascular Surgery classification.\(^{14}\)

Statistical Analysis

Data were pooled for analysis and are presented as mean ± standard deviation or absolute numbers (percentage). The CHEVAR and FEVAR techniques were compared using chi-square tests or Student t tests with a \(P\) value ≤0.05 considered statistically significant or the Mantel-Haenszel fixed effects approach with odds ratios (OR) and 95% confidence intervals when appropriate. Publication bias were adjusted with Funnel plots. Twelve-month results were analyzed for the outcomes of survival, reinterventions, and patency. All analyses were performed using XLStats v16.1 (ADDINSOFT) and RevMan v5.3 (The Nordic Cochrane Centre).

RESULTS

Five comparative studies were selected; their characteristics are listed in Table 1.\(^{15,16,17,18,19}\) A total of 126 patients were included in the CHEVAR group (174 target vessels) and 227 in the FEVAR group (510 target vessels). Patients were significantly older in the CHEVAR group (75.8 years ± 1.9 years vs 72.6 years

<table>
<thead>
<tr>
<th>References</th>
<th>Recruitment Period</th>
<th>Location</th>
<th>Treatment</th>
<th>Patients (No.)</th>
<th>Age (years)</th>
<th>Aneurysm Diameter (mm)</th>
<th>Proximal Sealing Zone</th>
<th>No of reconstructed vessels</th>
<th>Follow-up (Mo.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Donas et al, 2012(^{15})</td>
<td>2008-2010</td>
<td>Germany</td>
<td>CHEVAR</td>
<td>30</td>
<td>74 ± 7</td>
<td>62</td>
<td>7-8</td>
<td>38</td>
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<tr>
<td></td>
<td></td>
<td>Finland</td>
<td>FEVAR</td>
<td>29</td>
<td>74 ± 6</td>
<td>65</td>
<td>7-8</td>
<td>44</td>
<td>13</td>
</tr>
<tr>
<td>Suominen et al, 2013(^{16})</td>
<td>2007-2011</td>
<td>France</td>
<td>CHEVAR</td>
<td>7</td>
<td>79</td>
<td>65 ± 7</td>
<td>8</td>
<td>9</td>
<td>22</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>FEVAR</td>
<td>21</td>
<td>73</td>
<td>65 ± 7</td>
<td>8</td>
<td>54</td>
<td>22</td>
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<tr>
<td>Banno et al, 2014(^{17})</td>
<td>2006-2013</td>
<td>France</td>
<td>CHEVAR</td>
<td>38</td>
<td>74 ± 9</td>
<td>66 ± 15</td>
<td>8</td>
<td>60</td>
<td>12</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>FEVAR</td>
<td>80</td>
<td>74 ± 9</td>
<td>59 ± 9</td>
<td>8</td>
<td>194</td>
<td>14</td>
</tr>
<tr>
<td>Ronchey et al, 2015(^{18})</td>
<td>2007-2013</td>
<td>France</td>
<td>CHEVAR</td>
<td>20</td>
<td>74 ± 6</td>
<td>68 ± 24</td>
<td>7-8</td>
<td>28</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>FEVAR</td>
<td>7</td>
<td>74 ± 6</td>
<td>68 ± 24</td>
<td>6-8</td>
<td>20</td>
<td>9</td>
</tr>
<tr>
<td>Caradu et al, 2016(^{19})</td>
<td>2010-2015</td>
<td>CHEVAR</td>
<td>31</td>
<td>75 ± 7</td>
<td>68 ± 17</td>
<td>7-8</td>
<td>6-8</td>
<td>198</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FEVAR</td>
<td>90</td>
<td>71 ± 8</td>
<td>58 ± 10</td>
<td>6-8</td>
<td>198</td>
<td>17</td>
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</table>
± 1.5 years in the FEVAR group; \( P = .02 \) and there were significantly fewer male patients in the CHEVAR group (108 patients [85.7%] vs 217 [95.6%]; \( P = .006 \). Mean aneurysm diameter was 65.3 mm ± 2.5 mm in the CHEVAR group vs 61.8 mm ± 3.8 mm in the FEVAR group (\( P = .18 \)). Thirty patients treated by CHEVAR were symptomatic (23.8%, including 4 ruptured aneurysms [3.2%]), while patients treated by FEVAR were always elective. A history of prior aortic surgery was reported in 28 patients (22.2%) in the CHEVAR group vs 15 (6.6%) in the FEVAR group (\( P = .13 \)).

There were significantly fewer reconstructed vessels per patient treated by CHEVAR (1.4 ± 0.1 vs 2.3 ± 0.5; \( P = .004 \)). The operative and fluoroscopy times and the amount of contrast media were not significantly lower after CHEVAR (Table 2). Technical success rate, defined as absence of conversion, intraoperative mortality, type I or III EL with patency of the target vessels, was 92.9% after CHEVAR vs 91.2% after FEVAR (OR = 1.19; 95% CI: 0.40, 3.55).

The 30-day mortality rate was 4.8% after CHEVAR vs 4.4% after FEVAR (OR = 0.64; 95% CI: 0.23, 1.76). The 12-month overall target vessels patency rate was 95.9% after CHEVAR vs 97.8% after FEVAR (OR = 0.57; 95% CI: 0.17, 1.90). The 12-month rates of type I EL (3.7% vs 1.7%; OR = 0.32; 95% CI: 0.08, 1.32), type II EL (6.3% vs 10.1%; OR = 1.26; 95% CI: 0.55, 2.89), and type III EL (0.0% vs 0.9%; OR = 1.27; 95% CI: 0.13, 12.78) did not differ significantly between both techniques; neither did the rates of secondary interventions (10.0% vs 13.6%; OR = 1.23; 95% CI: 0.53, 2.88), overall mortality (9.6% vs 10.5%; OR = 0.77; 95% CI: 0.31, 1.87), and aneurysm-related mortality, defined as death from any cause within 30 days of the primary EVAR procedure or any death due to aneurysm rupture or device complication (4.8% vs 4.4%; OR = 0.64; 95% CI: 0.23, 1.76) (Figure 3).

### DISCUSSION

CHEVAR has gained increasing popularity during the last decade. The advantages of this technique include off-the-shelf and widespread availability for emergent treatment, whereas the production time for custom designed FEVAR ranges between 6 to 8 weeks. Also, the cost of CHEVAR is lower and it allows for the use of low-profile devices in case of hostile iliac accesses.\(^{20,21}\) However, with the FDA approval of the on-label solution offered by FEVAR and branched EVAR, concerns regarding the CHEVAR approach have been raised.

In a recent and extensive review by Yaoguo et al of 42 studies with 2,264 patients (4,413 vessels) undergoing FEVAR or CHEVAR,\(^{22}\) results showed higher aneurysm-related mortality after CHEVAR (3.2% after CHEVAR vs 1.4%, \( P = .02 \)). However, our meta-analysis did not show any significant difference at 12-month

### Table 2: Pooled Data Analyses of Perioperative Findings

<table>
<thead>
<tr>
<th>Outcomes</th>
<th>CHEVAR</th>
<th>FEVAR</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operative time (min)</td>
<td>144.5 ± 41.0</td>
<td>216.3 ± 49.7</td>
<td>0.07</td>
</tr>
<tr>
<td>Fluoroscopy time (min)</td>
<td>50.3 ± 11.2</td>
<td>66.3 ± 26.6</td>
<td>0.3</td>
</tr>
<tr>
<td>Contrast medium (mL)</td>
<td>122.8 ± 25.6</td>
<td>136.8 ± 15.1</td>
<td>0.4</td>
</tr>
<tr>
<td>Technical success rate (%)</td>
<td>117 (92.9)</td>
<td>207 (91.2)</td>
<td>0.8</td>
</tr>
<tr>
<td>Number of reconstructed vessels/patient</td>
<td>1.4 ± 0.1</td>
<td>2.3 ± 0.5</td>
<td>0.004</td>
</tr>
</tbody>
</table>
follow-up in terms of overall mortality or aneurysm-related mortality. One hypothesis is that given the assessment of urgency in most CHEVAR cases, more deaths consequently occurred during the first 30 days following treatment. However, perioperative mortality and in-hospital mortality did not differ significantly between both techniques. Another hypothesis is the potentiality of aneurysmal degeneration in relation to EL and especially type Ia EL due to the gutters. This remains one major concern regarding CHEVAR, and even if our meta-analysis and this review could not demonstrate a significant difference compared to FEVAR, a tendency remains toward higher rates of type Ia EL with this technique (3.4% after CHEVAR vs 2.0%; \( P = .09 \)).

The majority of type Ia ELs detected intraoperatively resolve with prolonged balloon inflation, and most others detected on immediate postoperative computed tomography angiography (CTA) spontaneously disappear. Embolization possibilities for the remaining ELs are currently under development with encouraging results using coils or Onyx liquid embolic agent (Covidien), showing a 59% rate of technical success with no EL on control imaging and 71% rate of good clinical outcome without sac increase. However, persisting endotension could lead to aneurysm rupture in the long term, even in the absence of significantly higher rates of aneurysm diameter increase (1.6% after CHEVAR vs 1.1%, \( P = .44 \)). Moreover, if the patient needs the repair to be extended further up due to aortic neck degeneration, the secondary procedure is more complicated after CHEVAR compared to FEVAR. As a matter of fact, after FEVAR an additional cuff will usually suffice but a new cannulation of the chimneys will be necessary to extend them proximally, with the consequent increased risk of occlusion due to longer chimneys, while open surgery is often not an option in these high-surgical-risk patients.

Another major concern is the target vessel’s long-term patency. We only analyzed early-term results, with a 12-month follow-up duration. However, there was already a tendency toward lower patency rates after CHEVAR. Nonetheless, it seems important to mention that patency rates for FEVAR were high compared to the literature results. In a systematic review by Di et al on 12 FEVAR studies and 776 patients (1,728 vessels), the 12-month patency rate was 94.5%. These results compare well with those of CHEVAR recently reported in the PERICLES registry, with a 17-month primary patency rate of 94.0%. The review by Yaoguo et al also reported an absence of significant difference between both technique with a 3.4% rate of occlusions or stenosis in the CHEVAR group vs 3.6% in the FEVAR group \( (P = .79) \).

Another important fact to take into consideration is the evolution of renal function after EVAR. A study conducted in our center recently reported the absence of significant difference in terms of renal resistive index, estimated glomerular filtration rate, and incidence of acute kidney injury or chronic kidney disease between chimney and fenestrated grafts. Procedure and fluoroscopy time as well as quantity of contrast medium, which contribute to renal function deterioration, were inferior with CHEVAR but the difference did not reach statistical significance in this meta-analysis. Moreover, this must be seen in context, considering the significantly lower number of reconstructed vessels. This number probably reflects the lower proximal
extent of aneurysms in patients treated by CHEVAR, because most centers only perform this technique when one or two target vessel reconstructions are needed, to limit the risk of type Ia EL.

The reintervention rate, which could be considered an indicator of successful endovascular treatment in the long term, did not differ significantly between both techniques in our meta-analysis. However, in the review by Yaoguo et al, FEVAR was associated with a higher reintervention rate (5.6% vs 11.7%, \(P=.001\)). The need for at least one reintervention was also reported to be 37% during long-term follow-up at the Cleveland Clinic, 29% being related to EL and 26% to the target vessels. Less complex designs were complicated by an increased risk of type I EL over time (10.4% for renal fenestrations only vs 1.9% for others, \(P<0.01\)) and as operators acquired experience, aortic reconstruction was extended more proximally in the same anatomical configurations. In the systematic review by Di et al, reintervention was needed in 17.6% of the cases at 12 months, and loss of renal artery patency was the leading reason (24.1%). The results of the PERICLES registry seem to suggest that CHEVAR could lead to lower reintervention rate (6.6% at 17 months), but longer term results are definitely needed to confirm this impression.

Recently, chimney endovascular aortic sealing (CHEVAS) has been reported as an alternative treatment option in highly selected cases of either ruptured aneurysms or situations where the implantation of on-label devices is hampered by anatomical constrains. It could present the advantage of lowering the risks of type II but also type Ia EL and the consequent rates of reintervention. The establishment of “off-the-shelf” devices that can be used for 50% to 70% of anatomies conventionally encountered in this type of procedure is also in progress. However, availability of these is far from widespread, consequences over target vessels patency are still unknown, and treatment options will still have to be provided for ineligible patients. Hence, it appears that CHEVAR and FEVAR are here to stay and not a transient bridge toward future technology.

There are some limitations to the results presented in this meta-analysis. Patients were not comparable between both groups, as CHEVAR patients presented with more comorbidities and more challenging anatomicies, while FEVAR patients presented with more complex designs (more target vessels with more celiac trunk and superior mesenteric artery reconstructions). Publication bias must also be acknowledged because no randomized control trials are available on this matter due to ethical difficulties. Hence, 2 studies were retrospective while 3 were prospective, and the assignment to each treatment option was mostly chosen upon clinical presentation and anatomical configurations. However, heterogeneity between studies remained low up to 12 months, and data were available on each endpoint of interest for every study selected in this meta-analysis.

**CONCLUSION**

Both CHEVAR and FEVAR are safe and effective in treating complex aortic aneurysms in the hands of experienced surgeons in high-volume centers using careful patient selection. They are important complementary strategies with numerous advantages and limits depending on the anatomy and clinical presentation of the patient. Hence, both should remain in the armamentarium of physicians treating complex aortic aneu-
Aortic aneurysms, considering that off-the-shelf devices have just begun to be implemented with unknown long-term results and limited availability and eligibility.

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