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Perioperative Outcome of Endovascular Repair for Complex Abdominal Aortic Aneurysms

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Abstract

Introduction—As endovascular techniques (EVAR) continue to advance, eligibility of patients with anatomically complex abdominal aortic aneurysms (AAA) for EVAR is increasing. However, it remains largely unclear whether complex EVAR is associated with favorable outcome over conventional open repair and how outcomes compare to infrarenal EVAR. The purpose of this study was to examine perioperative outcomes of patients undergoing complex EVAR, focusing on differences with complex open repair and standard infrarenal EVAR.

Methods—We identified all patients undergoing non-ruptured complex EVAR, complex open repair, and infrarenal EVAR in the Targeted Vascular Module from the American College of Surgeons National Surgical Quality Improvement Program. Aneurysms were considered complex if the proximal extent was juxta- or suprarenal, and/or when the Cook Zenith Fenestrated endograft was used. Independent risks were established using multivariable logistic regression analysis.

Results—A total of 4584 patients were included, with 411 (9.0%) undergoing complex EVAR, 395 (8.6%) complex open repair, and 3778 (82.4%) infrarenal EVAR. Perioperative mortality following complex EVAR was 3.4% vs. 6.6% after open repair (P=.038), and 1.5% after infrarenal EVAR (P=.005). Postoperative acute kidney injuries occurred in 2.3% of complex EVAR patients vs. 9.5% of those undergoing complex open repair (P<.001), and 0.9% of infrarenal EVAR patients (P=.007). Compared to complex EVAR, complex open repair was an independent predictor of 30-day mortality (OR: 2.2, 95% CI:1.1–4.4), renal function deterioration (4.8, 2.2–10.5), and any complication (3.7, 2.5–5.5). When comparing complex to infrarenal EVAR, infrarenal EVAR was associated with favorable 30-day mortality (0.5, 0.2–0.9), and renal outcome (0.4, 0.2–0.9).

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Conclusions—In this study assessing the perioperative outcomes of patients undergoing repair for anatomically complex AAAs, complex EVAR had fewer complications compared to complex open repair, but –in turn– did carry a higher risk of adverse outcomes than infrarenal EVAR. Further research is warranted to determine whether the benefits of EVAR compared to open repair for complex AAA treatment are maintained during long-term follow-up.

Introduction

Endovascular repair (EVAR) of an abdominal aortic aneurysm (AAA) is associated with lower perioperative mortality, as well as lower rates of complications, need for transfusions, and length of stay compared to open repair.[1–4] Because of these benefits, the utilization of EVAR has rapidly increased since its introduction in 1996,[5] with over 80% of infrarenal AAA repairs now being performed using endovascular treatment.[6–8] Due to inadequate proximal seal zone, standard endovascular repair cannot be used for juxta- and suprarenal aneurysms (complex AAA), which has been reported to make up as much as 20% of all AAAs.[9–11]

Through advancements in endovascular treatment techniques, including chimney, fenestrated and branched stent grafts, EVAR can now be offered to patients with complex proximal neck anatomy.[12] A large national series from the United Kingdom demonstrated that fenestrated endovascular repair can be performed with a high degree of technical and clinical success.[13] However, most feasibility studies are institutional based and therefore often limited to small numbers of patients.[14–18] Moreover, they usually did not compare outcome of complex EVAR to that of conventional open repair. Efforts that did compare complex EVAR to open repair yielded conflicting results. While one study demonstrated favorable perioperative outcomes after open repair,[19] two other studies showed reduced 30-day morbidity and mortality associated with EVAR.[20, 21] Adding to the confusion, two systematic reviews found perioperative benefits favoring EVAR,[22, 23] while another review demonstrated a pooled perioperative mortality of 4.1% after both EVAR and open repair, with no difference in the complication rate.[24]

In addition, it has been suggested that complex EVAR is associated with increased risk of postoperative renal failure compared to uncomplicated infrarenal EVAR.[25, 26] However, limited comparative data exist for infrarenal versus complex EVAR, and the presumed differences in renal complications could previously not be confirmed.[27]

The purpose of this study was to assess the perioperative outcome following EVAR for complex aneurysms, focusing on differences with complex open repair, the alternative treatment option, and standard infrarenal EVAR using the newly available Targeted Vascular data set of the National Surgical Quality Improvement Program.

Methods

For this study, we used the Targeted Vascular data set from the American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP) database. The ACS NSQIP is a multi-institutional collaboration with 102 participating hospitals in the United States that prospectively collect clinical data of patients undergoing major surgery.

The NSQIP database includes demographics, comorbidities, intraoperative characteristics, and 30-day postoperative outcomes. The Targeted Vascular data set is a recently added module, which includes additional disease and procedure specific characteristics, and procedure-related outcomes chosen by vascular surgeons. All data collection is performed by trained clinical nurse reviewers and data abstractors. The validity of the ACS NSQIP has been confirmed in previous reports.[28–30] The database contains de-identified data only without any protected health information. Therefore, Institutional Review Board approval and patient consent were waived. Additional information on the ACS NSQIP and the Targeted Vascular data set are available on www.acsnsqip.org.

From the Targeted Vascular data set for years 2011 to 2013, we identified all elective open and endovascular abdominal aortic aneurysm repairs, by the treatment indication variable. Thoracoabdominal aneurysms, procedures coded as repair of a ruptured AAA (CPT: 38082, 35092, 35103), and cases with a postoperative diagnosis code for a ruptured AAA (ICD-9: 441.3) were excluded from this study. Additionally, late conversions were excluded from analysis of complex open repairs (CPT: 34830, 34831, 34832). Results on this group have been reported previously.[31] Early conversions were considered an outcome for EVAR patients and are therefore included in all analyses as EVAR patients. The remaining cohort was subsequently divided in three groups in accordance with both treatment modality and proximal aneurysm extent: complex EVAR, complex open repair, and infrarenal EVAR. A complex aneurysm was defined as an aneurysm with either a juxtarenal or suprarenal proximal extent. Aneurysms coded as pararenal, which is separately defined as an AAA involving the origin of the renal arteries according to the NSQIP, were also considered complex. Data on proximal extent of the aneurysm were obtained directly from operative reports by trained clinical reviewers. All aneurysms treated with the Cook Zenith Fenestrated endograft, which is currently the only fenestrated graft approved by the Food and Drug Administration, were also considered complex. Complex open repair patients with infrarenal aortic clamping were excluded. For patients undergoing open repair, a visceral vessel reconstruction was defined as mentioning of a CPT code for visceral vessel reconstruction (CPT: 35361), or mentioning of a visceral vessel reconstruction in the Targeted module.

Groups were compared on baseline and operative characteristics, as well as postoperative outcomes. Postoperative outcomes included 30-day mortality, and in-hospital adverse outcomes such renal function deterioration, ischemic colitis, leg ischemia, wound complications, shock, sepsis, and length of ICU and hospital stay. Renal function deterioration was defined as a rise in creatinine of >2 mg/dl from preoperative value, and/or requirement of hemodialysis, peritoneal dialysis, hemofiltration, hemodiafiltration, or ultrafiltration within 30 days of the operation. Patients on dialysis preoperatively were excluded for analysis of renal outcomes. Ischemic colitis was defined as having symptoms of ischemic colitis and/or confirmation of the diagnosis on diagnostic sigmoidoscopy or colonoscopy. Patients with SIRS, sepsis, or septic shock prior to surgery were not included for postoperative sepsis and shock analysis. Wound complications included superficial, deep, and organ space infections. In order to identify differences in postoperative morbidity aside from death, 30-day mortality was not included in the any complication variable.

Statistical analyses

Categorical variables are presented as counts and percentages, and continuous variables as mean ± standard deviation. Differences between treatment groups were assessed using $\chi 2$ and Fisher's exact tests for categorical variables and Student's t-test for continuous variables, where appropriate. To assess independent risks associated with treatment approaches, we used multivariable logistic regression analysis. Baseline characteristics were univariately tested, and predictors with a P-value <.1 were added to the multivariable model. Age was included in all models, regardless of the univariable association. Risk-adjusted comparisons of complex EVAR to complex open repair and infrarenal EVAR were performed separately, and different models were constructed for each analysis. All tests were two-sided and significance was considered when P-value < .05. Statistical analysis was performed using the IBM SPSS Statistics 21 (IBM Inc., Chicago, IL).

Results

A total of 4584 patients were included, with 411 (9.0%) undergoing complex EVAR, 395 (8.6%) complex open repair, and 3778 (82.4%) underwent EVAR for an infrarenal (noncomplex) AAA.

Baseline characteristics

Baseline characteristics are detailed in Table I. The complex EVAR group was older than the complex open repair group (74.9 vs. 72.2 years, P<.001), consisted of fewer females (22.4% vs. 33.2%, P=.001), and more non-white patients (11.1% vs. 5.4%, P=.005). In terms of comorbidities, we found that complex EVAR patients more often had insulin-dependent diabetes (3.9% vs. 1.3% P=.019), had a higher preoperative creatinine (1.22 vs. 1.09 mg/dl, P=.006), and were more commonly on dialysis (2.9% vs. 0.8%, P=.034). Conversely, complex EVAR patients were less often current smokers (29.2% vs. 45.6%, P<.001).

Comparing the complex EVAR patients to the infrarenal EVAR patients, those undergoing repair for a complex AAA were more commonly dialysis dependent (2.9% vs. 0.9%, P<.001), more often had heart failure (4.1% vs. 1.6%, P<.001), and tended towards a higher preoperative creatinine (1.22 vs. 1.14 mg/dl, P=.055). In addition, obesity, defined as a BMI higher than 30 kg/m^2, was less common among complex EVAR patients compared to infrarenal EVAR patients (26.8% vs. 31.7%, P=.040).

Operative and anatomical characteristics

Complex EVAR was associated with shorter operative time compared to complex open repair (184 vs. 269 min., P<.001), while taking significantly longer than infrarenal EVAR (146 min, P<.001, Table IIA). Complex EVAR patients had a smaller aneurysm diameter compared to complex open repair patients (5.9 vs. 6.2 cm, P=.015), but not significantly different from those undergoing infrarenal EVAR (5.7 cm, P=.058). In addition, the aneurysm of complex EVAR patients more often extended into the iliac arteries compared to open complex repair (69.7% vs. 43.2%, P<.001), and infrarenal EVAR (52.9%, P<.001). The complex EVAR group included 22 (5.4%) patients with an aneurysm labeled as infrarenal who were treated with the Cook Zenith Fenestrated graft. Among complex AAA patients undergoing open repair, 18.8% had a clamp location above the celiac artery, 45.4% between the superior mesenteric artery and the renal arteries, and 35.9% above one renal artery. A visceral vessel reconstruction during open repair was performed in 27.1% of patients.

Not surprisingly, complex EVAR patients more often received renal revascularization than those undergoing EVAR for an infrarenal AAA (30.4% vs. 4.1%, P<.001, Table IIB). No difference existed in main body device used between complex and infrarenal EVAR patients (P=.121).

Postoperative outcomes

Postoperative outcomes are detailed in Table IIIA. Mortality within 30-days was significantly lower after complex EVAR compared to complex open repair (3.4% vs. 6.6%, P=.038). Similarly, deterioration of renal function (2.3% vs. 9.5%, P<.001) and new dialysis requirement (1.3% vs. 6.1%, P<.001) occurred less frequently after complex EVAR than complex open repair. In addition, complex EVAR was associated with lower rates of ischemic colitis (1.0% vs. 4.6%, P=.002), myocardial infarction (0.7% vs. 4.3%, P=.001), pneumonia (1.2 vs. 7.6%, P<.001), prolonged ventilator dependence (1.9% vs. 14.4%, P<.001), reintubation (2.2% vs. 9.4%, P<.001), wound dehiscence (0.2% vs. 3.0%, P=.001), shock (0.7% vs. 2.8%, P=.031, respectively), return to the operating room (5.4% vs. 13.9%, P<.001), and postoperative blood transfusions (16.3% vs. 78.7%, P<.001). Also, length of ICU stay and hospital stay were significantly shorter for those undergoing complex EVAR compared to complex open repair (1.0 vs. 4.7, P<.001; 4.1 days vs. 11.3 days, P<.001, respectively).

In comparison to infrarenal EVAR, 30-day mortality was significantly higher after complex EVAR (3.4% vs. 1.5%, P=.005). Similarly, complex EVAR was associated with a higher rate of renal function deterioration (2.3 % vs. 0.9%, P=.007), postoperative blood transfusion (16.3%, vs. 10.2%, P<.001), and prolonged ventilator dependence (1.9% vs. 0.9%, P=.036). In addition, ICU length of stay (1.0 vs. 0.6, P=.003), and hospital length of stay (4.1 days vs. 2.9 days, P=.001) were both significantly longer after complex EVAR compared to infrarenal EVAR.

Outcomes of patients receiving the Cook Zenith Fenestrated endograft are shown in Table IIIB. Although not significant, this subanalysis demonstrated that patients undergoing placement of a Cook Zenith fenestrated graft had a similar, if not lower, 30-day mortality rate compared to all other complex EVAR patients (1.2% vs. 4.0%, P=.318). However, patients treated with the Cook Zenith Fenestrated endograft more frequently received blood transfusions postoperatively (25.0% vs. 14.1%, P=.016). Similar to the other complex EVAR patients, low occurrence rates were found for various adverse outcomes, such as renal function deterioration (2.4% vs. 2.2%, P=1.000), ischemic colitis (1.2% vs. 0.9%, P=1.000), leg ischemia (0% vs. 1.8%, P=.354), and pneumonia (1.2% vs. 1.2%, P=1.000). Hospital and ICU length of stay were also comparable to the other complex EVAR patients (4.6 vs. 4.0 days, P=.488; 1.4 vs. 0.9 days, P=.208, respectively).

Multivariable analyses

In multivariable analysis (Table IV), open repair for complex AAA was found to be an independent predictor of 30-day mortality (OR: 2.2, 95% CI: 1.1 – 4.4), renal function deterioration (OR: 4.8, 95% CI: 2.2 – 10.5), and any complication (OR: 3.7, 95% CI: 2.5 – 5.5) compared to complex EVAR. When comparing complex to infrarenal EVAR, infrarenal EVAR was associated with favorable 30-day mortality (OR: 0.5, 95% CI: 0.2 – 0.9), and renal outcome (OR: 0.4, 95% CI: 0.2 – 0.9), while no difference was found in the occurrence of any complication (OR: 0.8, 95% CI: 0.6 – 1.2). Given the invasive nature of open AAA repair and the routine need for postoperative blood transfusions, a postoperative transfusion was not included as a complication in this analysis. However, when a blood transfusion is considered a complication, complex EVAR is associated with an increased risk of any complication compared to infrarenal EVAR as well (OR: 0.7, 95% CI: 0.5 – 0.9). Within the complex EVAR group, no differences were found between patients treated with the Cook Zenith Fenestrated endograft and those treated using other grafts in multivariable analysis.

Discussion

This study demonstrates that endovascular repair provides a good alternative to open repair for the treatment of complex AAA. In addition to lower 30-day mortality, we found that EVAR was associated with a lower incidence of various adverse outcomes, including acute renal failure, ischemic colitis, return to the operating room, and length of stay. In comparison to infrarenal EVAR, complex EVAR was associated with a significantly increased perioperative mortality risk, as well as a higher frequency of several other adverse outcomes, most importantly an increased incidence of postoperative renal dysfunction.

At 3.4%, the mortality following complex EVAR is comparable to previous reports.[22, 32–34] Despite the fact that complex EVAR patients were older and in more frail health than those undergoing open repair, mortality was almost half of that following open repair (3.4% vs. 6.6%). After adjustment for the various health disparities, treatment of a complex AAA through open repair proved to be associated with two-and-half times higher mortality risk compared to EVAR. This is in line with the results of previously conducted studies by Canavati et al. and Tsilimparis et al., which found a similar mortality benefit for fenestrated EVAR.[20, 35] In contrast to what has been shown for open repair,[36] endovascular complex AAA repair was associated with increased mortality risks over infrarenal EVAR. A difference in operative stress between EVAR for infrarenal and complex AAA, as indicated by the longer operative time, may have contributed to the observed difference in occurrence of adverse outcomes in the perioperative period.

Our results indicated that complex EVAR was associated with lower rates of complications compared to complex open repair. Despite worse preoperative renal function, the avoidance of suprarenal clamping and the resulting renal ischemia led to fewer kidney injuries and fewer patients requiring new dialysis with complex EVAR. This favorable renal outcome of EVAR for complex AAA is in line with previous studies.[22, 23] A recent case-controlled study, however, demonstrated a higher frequency of acute kidney injury after complex endovascular repair with similar 1-year results as open repair.[37] When comparing absolute rates of postoperative renal dysfunction to prior reports, the occurrence of kidney injuries in this study is relatively low.[22, 23, 38, 39] The present results most likely underestimate the actual incidence in our cohort, which is the result of the relative strict definition for postoperative renal dysfunction employed by the NSQIP. In regards to mid-term and late renal outcomes, previous studies have reported good patency results of renal stents and chimneys.[13, 25, 26, 38, 40] Although close monitoring of the renal function is required, this further highlights the benefit of EVAR over open repair, particularly for patients with renal impairment.[41]

Similar to established short-term perioperative benefits of EVAR for infrarenal AAA, the incidence of adverse events such as respiratory and wound complications, ischemic colitis, leg ischemia, myocardial infarction, and return to the operating room were lower for complex EVAR versus open repair. Due to the less complicated postoperative period and invasiveness of procedure, length of stay following complex EVAR was almost one-third of that following open repair. It should be noted that as a result of the exclusion of conversions to open repair, the incidence of adverse outcomes may be relatively low. However, as demonstrated by previous studies, conversion surgery is rare and most conversions are not performed in an acute setting.[31, 42] As previously suggested,[25, 26] complex EVAR was associated with a higher frequency of postoperative renal dysfunction compared to infrarenal EVAR, although this did not translate into a higher need for dialysis in the postoperative period. This is in contrast to the study by Glebova et al., which showed no difference in renal complications between infrarenal EVAR and fenestrated EVAR using the non-Targeted NSQIP dataset.[27] This difference may be related to the fact that the definition for complex EVAR in the present study is based on the specific Targeted NSQIP variable for proximal aneurysm extent, while the definition in the Glebova study was established from billing coding prior to the commercial availability of fenestrated endografts.

Several studies have reported on differences in outcome between chimney and fenestrated grafts. These studies determined that no difference exists in mortality or in renal endpoints between chimneys and fenestrated endografts.[33, 43] Unfortunately, we were unable to identify the exact technical approach that was used beyond the type of main body device. Selective analysis of patients receiving the Cook Zenith Fenestrated graft revealed that these patients had a similar, if not lower, mortality rate compared to the other complex EVAR patients. However, this may simply reflect that those treated otherwise have more complex anatomy, and were therefore ineligible for the Cook Zenith Fenestrated graft, which led to a trend towards worse outcomes. Unfortunately we did not have this level of anatomic detail. For other perioperative complications, we found that the Cook Zenith Fenestrated patients had comparable occurrence rates to other complex EVAR patients, including adverse renal outcomes, despite an increased transfusion requirement. This is in line with results from a pooled data analysis on fenestrated stent grafts.[33]

This study has several limitations. First, since the Targeted Vascular dataset of the NSQIP is gathered through a registry, underreporting of events is possible. Second, we were unable to fully distinguish between treatment approaches in patients undergoing complex EVAR. However, as previously addressed, reports have shown no differences in perioperative outcomes between fenestrated endografts and chimney grafts.[33, 43] Third, as evidenced by the lower than expected proportion of complex EVARs undergoing concurrent renal stenting, the capture of this data point was thought to be unreliable and therefore limited our ability to identify snorkel repairs. We believe this is the result of variable reporting of renal stenting based on interpretation of its definition, since NSQIP clinical reviewers are instructed to capture renal stenting for renal artery stenosis. Due to a lack of detail in CPT codes for endovascular procedures, CPT coding could unfortunately not be used for the documentation of visceral vessel reconstruction in EVAR patients. For complex open repair, we found that 27% of patients underwent visceral artery reconstruction, which is similar to previous reports.[44] Unfortunately, the exact number of visceral artery reconstructions is not documented in this data set. Fourth, the NSQIP database lacks data on perioperative endoleaks and long-term outcomes, which precluded us from assessing differences in the occurrence of endoleaks and late reinterventions, as well as long-term renal function. This highlights the need for future studies investigating the long-term outcome of EVAR for complex AAA. Also, since we did not have access to postoperative serum creatinine values, we were unable to redefine renal dysfunction or use standardized formulas consistent with previous studies. In addition, due to the novelty of this recently added vascular module, validation studies have yet to be conducted for it. However, the ability of these same nurse reviewers to accurately abstract data from the medical record for the NSQIP in general has been confirmed previously.[28–30] Finally, it should be noted that patients were not randomized to undergo open repair or EVAR. Nevertheless, this study provides valuable new data on the operative outcome of complex AAA repair in both the open and endovascular setting, which may add to prospectively conducted research efforts.

In conclusion, this study demonstrates that as a result of advancements in endovascular treatment techniques, EVAR has become a good alternative to conventional open repair for treatment of anatomically complex aneurysms. Complex EVAR has fewer perioperative complications compared to complex open repair, but –in turn– is associated with increased perioperative risks compared to infrarenal EVAR. Further research is warranted to determine whether the favorable outcome of EVAR for complex AAA is maintained during long-term follow-up.

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References

1. Schermerhorn ML, O'Malley AJ, Jhaveri A, Cotterill P, Pomposelli F, Landon BE. Endovascular vs. open repair of abdominal aortic aneurysms in the Medicare population. N Engl J Med. 2008; 358(5):464–74. [PubMed: 18234751]
2. Prinssen M, Verhoeven EL, Buth J, Cuypers PW, van Sambeek MR, Balm R, et al. A randomized trial comparing conventional and endovascular repair of abdominal aortic aneurysms. N Engl J Med. 2004; 351(16):1607–18. [PubMed: 15483279]
3. Lederle FA, Freischlag JA, Kyriakides TC, Padberg FT Jr, Matsumura JS, Kohler TR, et al. Outcomes following endovascular vs open repair of abdominal aortic aneurysm: a randomized trial. JAMA. 2009; 302(14):1535–42. [PubMed: 19826022]
4. Greenhalgh RM, Brown LC, Kwong GP, Powell JT, Thompson SG. participants Et. Comparison of endovascular aneurysm repair with open repair in patients with abdominal aortic aneurysm (EVAR trial 1), 30-day operative mortality results: randomised controlled trial. Lancet. 2004; 364(9437): 843–8. [PubMed: 15351191]

5. Kent KC. Clinical practice. Abdominal aortic aneurysms. N Engl J Med. 2014; 371(22):2101–8. [PubMed: 25427112]
6. Schermerhorn ML, Bensley RP, Giles KA, Hurks R, O'Malley AJ, Cotterill P, et al. Changes in abdominal aortic aneurysm rupture and short-term mortality, 1995–2008: a retrospective observational study. Ann Surg. 2012; 256(4):651–8. [PubMed: 22964737]
7. Chadi SA, Rowe BW, Vogt KN, Novick TV, Harris JR, Derose G, et al. Trends in management of abdominal aortic aneurysms. J Vasc Surg. 2012; 55(4):924–8. [PubMed: 22226189]
8. Lederle FA, Freischlag JA, Kyriakides TC, Matsumura JS, Padberg FT Jr, Kohler TR, et al. Long-term comparison of endovascular and open repair of abdominal aortic aneurysm. N Engl J Med. 2012; 367(21):1988–97. [PubMed: 23171095]
9. Crawford ES, Beckett WC, Greer MS. Juxtarenal infrarenal abdominal aortic aneurysm. Special diagnostic and therapeutic considerations. Ann Surg. 1986; 203(6):661–70. [PubMed: 3521511]
10. Qvarfordt PG, Stoney RJ, Reilly LM, Skioldebrand CG, Goldstone J, Ehrenfeld WK. Management of pararenal aneurysms of the abdominal aorta. J Vasc Surg. 1986; 3(1):84–93. [PubMed: 3941485]
11. Taylor SM, Mills JL, Fujitani RM. The juxtarenal abdominal aortic aneurysm. A more common problem than previously realized? Arch Surg. 1994; 129(7):734–7. [PubMed: 8024454]
12. Browne TF, Hartley D, Purchas S, Rosenberg M, Van Schie G, Lawrence-Brown M. A fenestrated covered suprarenal aortic stent. Eur J Vasc Endovasc Surg. 1999; 18(5):445–9. [PubMed: 10610834]
13. British Society for Endovascular T, the Global Collaborators on Advanced Stent-Graft Techniques for Aneurysm Repair R. Early results of fenestrated endovascular repair of juxtarenal aortic aneurysms in the United Kingdom. Circulation. 2012; 125(22):2707–15. [PubMed: 22665884]
14. Verhoeven EL, Vourliotakis G, Bos WT, Tielliu IF, Zeebregts CJ, Prins TR, et al. Fenestrated stent grafting for short-necked and juxtarenal abdominal aortic aneurysm: an 8-year single-centre experience. Eur J Vasc Endovasc Surg. 2010; 39(5):529–36. [PubMed: 20202868]
15. Lee JT, Greenberg JI, Dalman RL. Early experience with the snorkel technique for juxtarenal aneurysms. J Vasc Surg. 2012; 55(4):935–46. discussion 45–6. [PubMed: 22244859]
16. Greenberg RK, Haulon S, Lyden SP, Srivastava SD, Turc A, Eagleton MJ, et al. Endovascular management of juxtarenal aneurysms with fenestrated endovascular grafting. J Vasc Surg. 2004; 39(2):279–87. [PubMed: 14743126]
17. XiaoHui M, Wei G, ZhongZhou H, XiaoPing L, Jiang X, Xin J. Endovascular repair with chimney technique for juxtarenal aortic aneurysm: a single center experience. Eur J Vasc Endovasc Surg. 2015; 49(3):271–6. [PubMed: 25631457]
18. Tolenaar JL, Zandvoort HJ, Moll FL, van Herwaarden JA. Technical considerations and results of chimney grafts for the treatment of juxtarenal aneursyms. J Vasc Surg. 2013; 58(3):607–15. [PubMed: 23684412]
19. Raux M, Patel VI, Cochennec F, Mukhopadhyay S, Desgranges P, Cambria RP, et al. A propensity-matched comparison of outcomes for fenestrated endovascular aneurysm repair and open surgical repair of complex abdominal aortic aneurysms. J Vasc Surg. 2014; 60(4):858–63. discussion 63–4. [PubMed: 24835042]
20. Tsilimparis N, Perez S, Dayama A, Ricotta JJ 2nd. Endovascular repair with fenestrated-branched stent grafts improves 30-day outcomes for complex aortic aneurysms compared with open repair. Ann Vasc Surg. 2013; 27(3):267–73. [PubMed: 23403330]
21. Bruen KJ, Feezor RJ, Daniels MJ, Beck AW, Lee WA. Endovascular chimney technique versus open repair of juxtarenal and suprarenal aneurysms. J Vasc Surg. 2011; 53(4):895–904. discussion -5. [PubMed: 21211934]
22. Nordon IM, Hinchliffe RJ, Holt PJ, Loftus IM, Thompson MM. Modern treatment of juxtarenal abdominal aortic aneurysms with fenestrated endografting and open repair--a systematic review. Eur J Vasc Endovasc Surg. 2009; 38(1):35–41. [PubMed: 19346140]
23. Katsargyris A, Oikonomou K, Klonaris C, Topel I, Verhoeven EL. Comparison of outcomes with open, fenestrated, and chimney graft repair of juxtarenal aneurysms: are we ready for a paradigm shift? J Endovasc Ther. 2013; 20(2):159–69. [PubMed: 23581756]

24. Rao R, Lane TR, Franklin IJ, Davies AH. Open repair versus fenestrated endovascular aneurysm repair of juxtarenal aneurysms. J Vasc Surg. 2015; 61(1):242–55. [PubMed: 25240242]
25. Haddad F, Greenberg RK, Walker E, Nally J, O'Neill S, Kolin G, et al. Fenestrated endovascular grafting: The renal side of the story. J Vasc Surg. 2005; 41(2):181–90. [PubMed: 15767996]
26. Lee JT, Varu VN, Tran K, Dalman RL. Renal function changes after snorkel/chimney repair of juxtarenal aneurysms. J Vasc Surg. 2014; 60(3):563–70. [PubMed: 24785683]
27. Glebova NO, Selvarajah S, Orion KC, Black JH 3rd, Malas MB, Perler BA, et al. Fenestrated endovascular repair of abdominal aortic aneurysms is associated with increased morbidity but comparable mortality with infrarenal endovascular aneurysm repair. J Vasc Surg. 2015; 61(3):604–10. [PubMed: 25499706]
28. Davis CL, Pierce JR, Henderson W, Spencer CD, Tyler C, Langberg R, et al. Assessment of the reliability of data collected for the Department of Veterans Affairs national surgical quality improvement program. J Am Coll Surg. 2007; 204(4):550–60. [PubMed: 17382213]
29. Shiloach M, Frencher SK Jr, Steeger JE, Rowell KS, Bartzokis K, Tomeh MG, et al. Toward robust information: data quality and inter-rater reliability in the American College of Surgeons National Surgical Quality Improvement Program. J Am Coll Surg. 2010; 210(1):6–16. [PubMed: 20123325]
30. Daley J, Forbes MG, Young GJ, Charns MP, Gibbs JO, Hur K, et al. Validating risk-adjusted surgical outcomes: site visit assessment of process and structure. National VA Surgical Risk Study. J Am Coll Surg. 1997; 185(4):341–51. [PubMed: 9328382]
31. Ultee KH, Soden PA, Zettervall SL, Darling J, Verhagen HJ, Schermerhorn ML. Conversion from endovascular to open abdominal aortic aneurysm repair. J Vasc Surg. 2016; 64(1):76–82. [PubMed: 27345505]
32. Amiot S, Haulon S, Becquemin JP, Magnan PE, Lermusiaux P, Goueffic Y, et al. Fenestrated endovascular grafting: the French multicentre experience. Eur J Vasc Endovasc Surg. 2010; 39(5): 537–44. [PubMed: 20093051]
33. Donas KP, Torsello G, Bisdas T, Osada N, Schonefeld E, Pitoulias GA. Early outcomes for fenestrated and chimney endografts in the treatment of pararenal aortic pathologies are not significantly different: a systematic review with pooled data analysis. J Endovasc Ther. 2012; 19(6):723–8. [PubMed: 23210868]
34. 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; 55(5):1497–503. [PubMed: 22236883]
35. Canavati R, Millen A, Brennan J, Fisher RK, McWilliams RG, Naik JB, et al. Comparison of fenestrated endovascular and open repair of abdominal aortic aneurysms not suitable for standard endovascular repair. J Vasc Surg. 2013; 57(2):362–7. [PubMed: 23044256]
36. Patel VI, Lancaster RT, Conrad MF, Lamuraglia GM, Kwolek CJ, Brewster DC, et al. Comparable mortality with open repair of complex and infrarenal aortic aneurysm. J Vasc Surg. 2011; 54(4): 952–9. [PubMed: 21723071]
37. Saratzis AN, Bath MF, Harrison SC, Sayers RD, Bown MJ. Impact of Fenestrated Endovascular Abdominal Aortic Aneurysm Repair on Renal Function. J Endovasc Ther. 2015; 22(6):889–96. [PubMed: 26359438]
38. Martin-Gonzalez T, Pincon C, Maurel B, Hertault A, Sobocinski J, Spear R, et al. Renal Outcomes Following Fenestrated and Branched Endografting. Eur J Vasc Endovasc Surg. 2015; 50(4):420–30. [PubMed: 26021528]
39. Karthikesalingam A, Bahia SS, Patel SR, Azhar B, Jackson D, Cresswell L, et al. A systematic review and meta-analysis indicates underreporting of renal dysfunction following endovascular aneurysm repair. Kidney Int. 2015; 87(2):442–51. [PubMed: 25140912]
40. Hiramoto JS, Chang CK, Reilly LM, Schneider DB, Rapp JH, Chuter TA. Outcome of renal stenting for renal artery coverage during endovascular aortic aneurysm repair. J Vasc Surg. 2009; 49(5):1100–6. [PubMed: 19233597]
41. Martin MC, Giles KA, Pomposelli FB, Hamdan AD, Wyers MC, Schermerhorn ML. National outcomes after open repair of abdominal aortic aneurysms with visceral or renal bypass. Ann Vasc Surg. 2010; 24(1):106–12. [PubMed: 20122465]

42. Schermerhorn ML, Buck DB, O'Malley AJ, Curran T, McCallum JC, Darling J, et al. Long-Term Outcomes of Abdominal Aortic Aneurysm in the Medicare Population. N Engl J Med. 2015; 373(4):328–38. [PubMed: 26200979]
43. Lee JT, Lee GK, Chandra V, Dalman RL. Comparison of fenestrated endografts and the snorkel/chimney technique. J Vasc Surg. 2014; 60(4):849–56. discussion 56–7. [PubMed: 24785682]
44. Sarac TP, Clair DG, Hertzer NR, Greenberg RK, Krajewski LP, O'Hara PJ, et al. Contemporary results of juxtarenal aneurysm repair. J Vasc Surg. 2002; 36(6):1104–11. [PubMed: 12469040]

Table I

Baseline characteristics

	EVAR complex	OR complex	EVAR infra	p-value	
	N=411	*N=395*	*N=3778*	*Complex EVAR vs. OR*	*Infra vs. complex EVAR*
Age – years (sd)	74.9 (8.1)	72.2 (8.3)	74.2 (8.6)	<.001	.160
Categories – N (%)				<.001	.788
<59 years	17 (4.1)	24 (6.1)	191 (5.1)	<.001	.788
60–69	90 (21.9)	125 (31.6)	898 (23.8)		
70–79	181 (44.0)	165 (41.8)	1573 (41.6)		
80–89	112 (27.3)	80 (20.3)	1015 (26.9)		
90+	11 (2.7)	1 (0.3)	101 (2.7)		
Female gender – N (%)	92 (22.4)	131 (33.2)	699 (18.5)	.001	.056
Race				.007	.006
American Indian/Alaska Native	1 (0.2)	2 (0.5)	3 (0.1)		
Asian	15 (3.6)	4 (1.0)	85 (2.2)		
Black or African American	26 (6.3)	14 (3.5)	185 (4.9)		
Native Hawaiian or Pacific Islander	2 (0.5)	0 (0)	2 (0.1)		
White	352 (85.6)	347 (87.8)	3255 (86.2)		
Unknown	15 (3.6)	28 (7.1)	248 (6.6)		
Comorbidities					
Hypertension – N (%)	343 (83.5)	336 (85.1)	3046 (80.6)	.531	.166
Diabetes – N (%)	63 (15.3)	44 (11.1)	618 (16.4)	.080	.591
Insulin-dependent diabetes – N (%)	16 (3.9)	5 (1.3)	105 (2.8)	.019	0.20
COPD – N (%)	80 (19.5)	93 (23.5)	674 (17.8)	.158	.416
Heart failure – N (%)	17 (4.1)	8 (2.0)	62 (1.6)	.084	<.001
Renal insufficiency – N (%)	79 (19.7)	59 (15.1)	622 (16.9)	.087	.167
Preoperative creatinine – N (%)	1.22 (.85)	1.09 (.43)	1.14 (.57)	.006	.055
Dialysis– N (%)	12 (2.9)	3 (0.8)	34 (0.9)	.034	<.001
BMI >30 – N (%)	110 (26.8)	99 (25.1)	1198 (31.7)	.582	.040
Current smoking – N (%)	120 (29.2)	180 (45.6)	1137 (30.1)	<.001	.706

OR: open repair; COPD: chronic obstructive pulmonary disease; BMI: Body Mass Index

Table IIA

Anatomical and intraoperative characteristics for all study groups

	EVAR complex	OR complex	EVAR infra	p-value	
	N=411	*N=395*	*N=3778*	*Complex EVAR vs. OR*	*Infra vs. complex EVAR*
Operative time – min (sd)	184 (100)	269 (108)	146 (70)	<.001	<.001
Diameter – cm (sd)	5.9 (2.6)	6.2 (1.4)	5.7 (1.6)	.015	.058
Indication – N (%)				.074	.108
Diameter	348 (88.1)	328 (83.9)	3304 (88.6)		
Dissection	2 (0.5)	1 (0.3)	28 (0.8)		
Embolization	2 (0.5)	1 (0.3)	20 (0.5)		
Symptomatic	23 (5.8)	47 (12.0)	281 (7.5)		
Thrombosis	10 (2.5)	9 (2.3)	43 (1.2)		
Prior unsatisf. EVAR	7 (1.8)	0 (0)	40 (1.1)		
Prior unsatisf. OR	3 (0.8)	5 (1.3)	12 (0.3)		
Distal extent – N (%)				<.001	<.001
Aortic	112 (30.3)	204 (56.8)	1539 (47.1)		
Common iliac	171 (46.2)	137 (38.2)	1304 (39.9)		
External iliac	38 (10.3)	9 (2.5)	181 (5.5)		
Internal iliac	49 (13.2)	9 (2.5)	242 (7.4)		

Table IIB

EVAR specific intraoperative characteristics

	EVAR complex	**OR complex**	**EVAR infra**	**p-value**
	N=411	***N=395***	***N=3778***	***Infra vs. complex EVAR***
Acute conversion – N (%)	3 (0.7)	-	21 (0.6)	.506
Access – N (%)				.100
Attempted percutaneous	5 (1.2)	-	33 (0.9)	
Bilateral cutdown	277 (67.4)	-	2441 (64.7)	
One groin cutdown	23 (5.6)	-	348 (9.2)	
Percutaneous bilateral	106 (25.8)	-	950 (25.2)	
Renal revascularization – N (%)	125 (30.4)	-	156 (4.1)	<.001
Lower extrem revasc – N (%)	19 (5.5)	-	138 (4.2)	.247
Access vessel repair – N (%)	42 (10.2)	-	284 (7.5)	.052
Hypogastric embolization – N (%)	27 (6.6)	-	248 (6.6)	.997
Main body device – N (%)				.121[a]
Cook Zenith	72 (17.5)	-	795 (21.0)	
Cook Zenith Fenestrated	84 (20.4)	-	0 (0)	
Cook Zenith Renu	3 (0.7)	-	39 (1.0)	
Endologix Powerlink	26 (6.3)	-	292 (7.7)	
Gore Excluder	95 (23.1)	-	1281 (33.9)	
Lombard Aorfix	0 (0)	-	2 (0.1)	
Medtronic AneuRx	1 (0.3)	-	7 (0.2)	
Medtronic Endurant	95 (23.1)	-	1130 (29.9)	
Medtronic TALENT	1 (0.2)	-	18 (0.5)	
TriVascular Ovation	4 (1.0)	-	36 (1.0)	
other	26 (6.3)	-	149 (3.9)	
not documented	4 (1.0)	-	29 (0.8)	

[a] analysis did not include patients receiving a Cook Zenith Fenestrated endograft.

Table IIIA

Postoperative outcomes for all study groups

	EVAR complex	OR complex	EVAR infra	p-value	
	N=411	*N=395*	*N=3778*	*Complex EVAR vs. OR*	*Infra vs. complex EVAR*
30-day mortality	14 (3.4)	26 (6.6)	57 (1.5)	0.038	.005
Creat rise >2 mg/dl – N (%)	9 (2.3)	37 (9.5)	32 (0.9)	<.001	.007
Requiring dialysis – N (%)	5 (1.3)	24 (6.1)	21 (0.6)	<.001	.096
Ischemic colitis – N (%)	4 (1.0)	18 (4.6)	19 (0.5)	.002	.276
Leg ischemia – N (%)	6 (1.5)	7 (1.8)	49 (1.3)	.725	.783
Pneumonia – N (%)	5 (1.2)	30 (7.6)	32 (0.8)	<.001	.447
>48 hour on ventilator	8 (1.9)	57 (14.4)	33 (0.9)	<.001	.036
Reintubation – N (%)	9 (2.2)	37 (9.4)	51 (1.3)	<.001	.174
Myocardial infarction – N (%)	3 (0.7)	17 (4.3)	52 (1.4)	.001	.364
CPR – N (%)	2 (0.5)	10 (2.5)	22 (0.6)	.019	1.000
Wound infection – N (%)	6 (1.5)	11 (2.8)	60 (1.6)	.191	.860
Wound dehiscence – N (%)	1 (0.2)	12 (3.0)	8 (0.2)	.001	.606
Return to OR – N (%)	22 (5.4)	55 (13.9)	148 (3.9)	<.001	.161
Pulmonary embolism	1 (0.2)	2 (0.5)	8 (0.2)	.617	.606
Stroke – N (%)	3 (0.7)	3 (0.8)	9 (0.2)	1.000	.106
Sepsis – N (%)	3 (0.7)	10 (2.5)	22 (0.6)	.051	.731
Shock – N (%)	3 (0.7)	11 (2.8)	14 (0.4)	.031	.229
Rupture 30-day – N (%)	0 (0)	1 (0.3)	2 (0.1)	.490	1.000
Early conversion – N (%)	3 (0.7)	-	21 (0.6)	-	0.655
≥1 postoperative transfusion	67 (16.3)	311 (78.7)	385 (10.2)	<.001	<.001
Any complication – N (%)	49 (12.0)	133 (33.7)	348 (9.2)	<.001	.077
Any complication – N (%)[α]	99 (24.1)	328 (83.0)	623 (16.5)	<.001	<.001
Hospital length of stay – days (sd)	4.1 (6.8)	11.3 (10.0)	2.9 (5.1)	<.001	.001
ICU length of stay – days (sd)	1.0 (2.4)	4.7 (4.9)	0.6 (1.7)	<.001	.003

[α] incidence of any complication when postoperative blood transfusions are included

Table IIIB

Postoperative outcomes for complex EVAR patients treated with the Cook Zenith Fenestrated graft and those treated otherwise

	Cook Zenith Fenestrated	Other Complex EVAR	P-value
	N=84	*N=327*	
30-day mortality	1 (1.2)	13 (4.0)	.318
Creat rise >2 mg/dl – N (%)	2 (2.4)	7 (2.2)	1.000
Requiring dialysis – N (%)	2 (2.4)	3 (1.0)	.284
Ischemic colitis – N (%)	1 (1.2)	3 (0.9)	1.000
Leg ischemia – N (%)	0 (0)	6 (1.8)	.354
Pneumonia – N (%)	1 (1.2)	4 (1.2)	1.000
>48 hour on ventilator	2 (2.4)	6 (1.8)	.669
Reintubation – N (%)	3 (3.6)	6 (1.8)	.397
Myocardial infarction – N (%)	1 (1.2)	2 (0.6)	.497
CPR – N (%)	0 (0)	2 (0.6)	1.000
Wound infection – N (%)	1 (1.2)	6 (1.8)	1.000
Wound dehiscence – N (%)	0 (0)	1 (0.3)	1.000
Return to OR – N (%)	5 (6.0)	17 (5.2)	.784
Pulmonary embolism	0 (0)	1 (0.3)	1.000
Stroke – N (%)	1 (1.2)	2 (0.6)	.497
Sepsis – N (%)	2 (2.4)	1 (0.3)	.108
Shock – N (%)	1 (1.2)	2 (0.6)	.497
Rupture 30-day – N (%)	0 (0)	0 (0)	1.000
Early conversion – N (%)	1 (1.2%)	2 (0.6%)	.499
≥1 postoperative transfusion	21 (25.0)	46 (14.1)	.016
Any complication – N (%)	10 (11.9)	37 (11.3)	.880
Any complication – N (%)[a]	25 (29.8)	72 (22.0)	.136
Hospital length of stay – days (sd)	4.6 (6.5)	4.0 (6.9)	.488
ICU length of stay – days (sd)	1.4 (3.5)	0.9 (2.1)	.208

[a] incidence of any complication when postoperative blood transfusions are included

Table IV

Adjusted associations between treatment groups and outcomes

30-day mortality[α]	***OR***	***95% CI***	***p-value***
EVAR complex	*Reference*	-	-
Open complex[α]	2.2	1.1 – 4.4	0.025
EVAR infrarenal[β]	0.5	0.2 – 0.9	0.014
Renal complication[β]	***OR***	***95% CI***	***p-value***
EVAR complex	*Reference*	-	-
Open complex[γ]	4.8	2.2 – 10.5	<.001
EVAR infrarenal[δ]	0.4	0.2 – 0.9	.017
Any complication[γ]	***OR***	***95% CI***	***p-value***
EVAR complex	*Reference*	-	-
Open complex[ε]	3.7	2.5 – 5.5	<.001
EVAR infrarenal[ζ]	0.8	0.6 – 1.2	.304

[α] adjusted for: age, gender, obstructive pulmonary disease

[β] adjusted for: age, gender, hypertension, insulin-dependent diabetes, preoperative renal insufficiency, preoperative dialysis, heart failure, obstructive pulmonary disease, obesity, current smoking, symptom status

[γ] adjusted for: age, preoperative renal insufficiency, obstructive pulmonary disease, obesity, symptom status

[δ] adjusted for: age, gender, insulin-dependent diabetes, preoperative renal insufficiency, obstructive pulmonary disease, obesity

[ε] adjusted for: age, gender, hypertension, preoperative renal insufficiency, obstructive pulmonary disease

[ζ] adjusted for: age, gender, nonwhite race, hypertension, insulin-dependent diabetes, preoperative renal insufficiency, preoperative dialysis, heart failure, obstructive pulmonary disease, obesity, symptom status