Title

Proximal Instructions for Use Violations in Elective Endovascular Aneurysm Repair in the Vascular Quality Initiative: Retrospective Analysis.

Journal

Journal of The American College of Surgeons, 237(4)

Authors

Ramirez, Joel
Govsyeyev, Nicholas
Sorber, Rebecca
et al.

Publication Date

2023-10-01

DOI

10.1097/XCS.0000000000000783

Peer reviewed

HHS Public Access
Author manuscript
J Am Coll Surg. Author manuscript; available in PMC 2024 October 01.

Published in final edited form as:
J Am Coll Surg. 2023 October 01; 237(4): 633–643. doi:10.1097/XCS.0000000000000783.

Proximal Instructions for Use Violations in Elective Endovascular Aneurysm Repair in the Vascular Quality Initiative: Retrospective Analysis

Joel L Ramirez, MD,
Division of Vascular and Endovascular Surgery, University of California, San Francisco, San Francisco, CA

Chan Zuckerberg Biohub, San Francisco, CA

Nicholas Govsyeyev, MD, MSCS,
Scripps Clinic, La Jolla, CA

Rebecca Sorber, MD,
Johns Hopkins University School of Medicine, Baltimore, MD

James C Iannuzzi, MD, MPH,
Scripps Clinic, La Jolla, CA

Andres S Schanzer, MD, FACS,
University of Massachusetts Medical School, Worcester, MA

Caitlin W Hicks, MD, MS, FACS,
Johns Hopkins University School of Medicine, Baltimore, MD

Mahmoud B Malas, MD, MHS,
University of California San Diego, San Diego, CA

Devin S Zarkowsky, MD, FACS
Division of Vascular and Endovascular Surgery, University of California, San Francisco, San Francisco, CA

Abstract

Correspondence address: Devin Zarkowsky, MD, Scripps Clinic, 9888 Genesse Ave, La Jolla, CA 92037. zarkowsky.devin@scrippshealth.org.

Author Contributions
Conceptualization: Ramirez, Sorber, Iannuzzi, Schanzer, Hicks, Malas, Zarkowsky
Data curation: Ramirez, Govsyeyev, Schanzer, Zarkowsky
Formal analysis: Ramirez, Govsyeyev, Sorber, Iannuzzi, Schanzer, Hicks, Malas, Zarkowsky
Investigation: Ramirez, Govsyeyev, Hicks, Malas, Zarkowsky
Methodology: Ramirez, Govsyeyev, Sorber, Iannuzzi, Schanzer, Hicks, Malas, Zarkowsky
Validation: Ramirez, Zarkowsky
Visualization: Ramirez
Writing – original draft: Ramirez, Govsyeyev, Sorber, Iannuzzi, Schanzer, Hicks, Malas, Zarkowsky
Writing – review & editing: Ramirez, Govsyeyev, Zarkowsky
Supervision: Zarkowsky

Disclosure Information: Dr Hicks receives speaking fees from Cook Medical Inc and WL Gore. Other authors have nothing to disclosure.

Supplemental digital content is available for this article.

BACKGROUND: Endovascular aneurysm repair (EVAR) is often attempted in patients with marginal anatomy. These patients' midterm outcomes are available in the Vascular Quality Initiative for analysis.

STUDY DESIGN: Retrospective analysis of prospectively collected data in the Vascular Quality Initiative from patients who underwent elective infrarenal EVAR between 2011 and 2018. Each EVAR was identified as either on- or off-instructions for use (IFU) based on aortic neck criteria. Multivariable logistic regression models were used to assess associations between aneurysm sac enlargement, reintervention, and type Ia endoleak with IFU status. Kaplan-Meier time-to-event models estimated reintervention, aneurysm sac enlargement, and overall survival.

RESULTS: We identified 5,488 patients with at least 1 follow-up recorded. Those treated off-IFU included 1,236 patients ([23%] mean follow-up 401 days) compared with 4,252 (77%) treated on-IFU (mean follow-up 406 days). There was no evidence of significant differences in crude 30-day survival (96% vs 97%; p = 0.28) or estimated 2-year survival (97% vs 97%; log-rank p = 0.28). Crude type Ia endoleak frequency was greater in patients treated off IFU (2% vs 1%; p = 0.03). Off-IFU EVAR was associated with type Ia endoleak on multivariable regression model (odds ratio 1.84 [95% CI 1.23 to 2.76]; p = 0.003). Patients treated off IFU vs on IFU experienced had increased risk of reintervention within 2 years (7% vs 5%; log-rank p = 0.02), a finding consistent with results from the Cox modeling (hazard ratio 1.38 [95% CI 1.06 to 1.81]; p = 0.02).

CONCLUSIONS: Patients treated off IFU were at greater risk for type Ia endoleak and reintervention, although they had similar 2-year survival compared with those treated on IFU. Patients with anatomy outside IFU should be considered for open surgery or complex endovascular repair to reduce the probability for revision.

Endovascular aneurysm repair (EVAR) is the most frequent treatment for abdominal aortic aneurysms (AAA) in the US today.[1] Decreased perioperative morbidity and improved short-term overall survival with EVAR compared with open surgery are factors often cited for contributing to this shift.[2] Level-I evidence established nearly 2 decades ago demonstrates survival between open and endovascular repair converging at 2 years, suggesting that patient factors or implantation technique may contribute to diminished benefit after EVAR beyond the 2-year follow-up.[3]

Anatomy often constrains the on-label application of EVAR detailed in the individual device manufacturer's instructions for use (IFU). These criteria depend on infrarenal aortic neck length, neck diameter, infra- and suprarenal neck angle, and iliac artery diameter.[4] Technologic revision during the course of 25 years increased the proportion of patients with suitable anatomy, but anatomic contraindications to EVAR occur frequently in practice, particularly in women.[5] Nonadherence to proximal IFU criteria approaches 50% in clinical practice because many physicians seek to avoid open surgery or complex endovascular repair despite lacking data on long-term outcomes after infrarenal EVAR performed off IFU.[6–10]

Several single-institution series found no difference in mortality or aneurysm-related interventions between off- and on-IFU infrarenal EVAR.[7,10] Evidence from several multicenter series showed that nonadherence to IFU may increase the risk of long-term complications. A recent meta-analysis found no difference in reinterventions but did find increased mortality in patients treated with off-IFU infrarenal EVAR.[6,8,9] No clear guidance exists regarding the risk-benefit profile for off-IFU infrarenal EVAR in the elective setting. The aim of this study was to compare midterm (within 2 years) outcomes for patients treated with off-IFU infrarenal EVAR to outcomes for patients receiving on-IFU EVAR in the elective setting. We hypothesized that patients treated with EVAR off IFU had decreased midterm overall survival and lower risk of revision after EVAR compared to patients treated on IFU.

METHODS

Study design

This is a retrospective cohort study using data from the Society for Vascular Surgery Vascular Quality Initiative (VQI) database.[11] The VQI database contains preoperative risk factors, intraprocedural variables and postoperative outcomes for several distinct vascular procedures, including EVAR. Data included in VQI datasets are from more than 780 participating centers, including both community and academic practices. Information is available on patient aortic neck length, angle, and diameter, as well as graft characteristics. Each EVAR procedure recorded in VQI captures the graft length and diameter in addition to the patient's proximal AAA neck characteristics, which can allow for the identification of grafts based on the companies' different specifications. Graft diameters and lengths, as well as iliac limb characteristics, each patient's graft manufacturer was determined. We then used anatomic measurements of the proximal AAA neck present in VQI compared to the manufacturer's IFU criteria (see Table, Supplemental Digital Content 1, http://links.lww.com/JACS/A282), to determine whether or not implantation adhered.

The study cohort was developed by identifying all patients who underwent endovascular infrarenal AAA repair during 2011 through 2018. Only patients with 1 or more follow-up visits were included. Patients in whom levels of urgency were designated as urgent or emergent were excluded. This resulted in 21,226 unique patients excluded from analyses. Proximal neck anatomy including diameter, length, and angulation, were compared with the IFU dimensions specific to the devices deployed in each case; a case was designated off IFU if any of the aneurysm neck dimensions differed from those prescribed by the device manufacturer's IFU. Iliac anatomy was underreported in the database and was not included as part of the IFU determination. (For a summary of the IFU criteria associated with devices in this study, see Table, Supplemental Digital Content 1, http://links.lww.com/JACS/A282.)

The Institutional Review Board at the University of California San Francisco approved this study and waived informed consent requirements because this was a retrospective analysis of a de-identified data source.

Study outcomes

The primary outcomes of this study were midterm survival and freedom from reintervention. We define "midterm" as the period between 30 days postprocedure and 5 years follow-up, when long-term outcomes customarily begin in surgical literature. Secondary outcomes included AAA sac enlargement, intraoperative and type Ia endoleak, and 30-day survival.

For midterm follow-up, the index operation was time zero and the last follow-up was based on what was collected by the VQI at the time of data query.

Statistical analysis

Outcomes were compared between the on- vs off-IFU groups using univariable analysis including χ^2 for categorical variables, Student's *t*-test for continuous variables with approximately normal distributions as determined graphically, and Mann-Whitney test for continuous variables with other distributions. Variables with more than 5% of values missing were excluded from the analysis. Cox proportional hazards models were used for time-to-event analyses. A multivariable logistic regression model was used to assess patient factors (anatomic, technical, and comorbidities) that may have ultimately resulted in a type Ia endoleak. Explanatory variables with $p < 0.05$ in the univariable comparison were included in multivariable Cox proportional hazards models aimed at modeling AAA sac enlargement and reintervention at 2 years postprocedure. Significant characteristics were also included in a multivariable logistic regression model to identify variables statistically associated with type Ia endoleak. Multivariable models were adjusted for log of the average yearly center volume, physician, sex, previous infrarenal aortic surgery, procedure time, fluoroscopy time, contrast volume, infrarenal neck length, diameter, and angle, as well as deidentified grafts. These variables were all included in the initial models and removed via backwards stepwise elimination if $p > 0.1$. Variables that changed measures of model discrimination, including area under the receiver operating curve, multivariable logistic regression, or Harrell's c-statistic (Cox), more than 0.1 on removal were returned to the model. Hosmer-Lemeshow goodness of fit assessed the ability of the equation generated from a multivariable model to fit the data range. Somers' D reports the strength of association between the exposure and outcome variables incorporated into the Cox models. Kaplan-Meier time-to-event curves with log-rank tests were used to summarize and compare freedom from reintervention, AAA sac enlargement, and survival for on- vs off-IFU patient groups in unadjusted univariate analysis.

All statistical analyses were performed using Stata v.15.1 (StataCorp LP, College Station, TX). A 2-sided $p < 0.05$ was considered to be statistically significant for reporting analyses in this study. There was no adjustment for multiple testing.

RESULTS

Baseline demographics and preoperative characteristics

There were 26,714 unique patients collected in the VQI EVAR dataset between 2011 and 2018, with 5,488 patient records having at least 1 follow-up visit recorded and containing anatomy and graft information allowing for classification of either on IFU or off IFU. Characteristics of patients treated on and off IFU are summarized in Table 1. The off-IFU group included 1,236 patients (23%) compared to 4,252 (77%) that were treated on IFU. Patients treated off IFU were more frequently operated on at facilities with lower average annual EVAR volume (median 18 vs 19 patients per year), older (74 vs 73 years), female (27% vs 15%), non-White (10% vs 7%), and diagnosed with COPD (33% vs 30%; all p <

0.05). Additionally, off-IFU patients were less likely to smoke and had slightly lower mean BMI.

Compared with patients treated on IFU, those treated off IFU were more likely to be deemed unfit for open repair (18% vs 14%) by the implanting surgeon and have a history of previous infrarenal aortic surgery (7% vs 4%; all $p < 0.05$). Maximum aneurysm diameter and preoperative anticoagulation were similar between both groups. Proximal neck anatomy in the off-IFU group included shorter (21 vs 28 mm; $p < 0.001$), more angulated necks (38% vs 13% with more than 45 degrees; $p < 0.001$).

Intraoperative details

Intraoperative characteristics are presented in Table 1. The off-IFU EVAR group had a significantly longer median operative time (120 vs 108 minutes), median fluoroscopy time (20 vs 18 minutes), and a higher mean contrast volume (100 vs 89 mL) when compared with the on-IFU group (all $p < 0.05$). Bifurcated grafts were less common in the off-IFU group (93% vs 95%), while uni-iliac (6% vs 4%) and aorto-aortic (2% vs 1%) configurations were used more frequently in off-IFU patients (all $p < 0.05$). Additionally, the off-IFU group had significantly more oversizing (median 21% vs 17%) and required more proximal aortic extensions (22% vs 16%) than the on-IFU group (all $p < 0.05$). Graft 2 was more frequently used in off-IFU patients while graft 3 was more common for those receiving on-IFU EVAR. Off-IFU EVAR patients demonstrated twice the frequency of type Ia endoleaks at the end of the index case in comparison with the on-IFU group (6% vs 3%; $p < 0.001$). Conversion to an open procedure rarely occurred (n = 2) and was not statistically different between the 2 groups.

In-hospital outcomes

Postoperative complications, including stroke, myocardial infarction, new dysrhythmia, re-intubation, or intestinal ischemia were not different between patients who underwent off- vs on-IFU EVAR (Table, Supplemental Digital Content 2, http://links.lww.com/JACS/A282). Acute kidney injury was more common after off-IFU EVAR (4% vs 2%; $p = 0.008$) although there was no difference in new dialysis requirements. In-hospital reintervention, hospital length of stay, and discharge disposition were not different between the 2 groups. Survival at 30 days was not different between patients who underwent off-IFU and on-IFU EVAR.

Midterm outcomes

Midterm outcomes after both off- and on-IFU EVAR are presented in Table 2. Average follow-up was 401 days in the off-IFU group and 406 days in the on-IFU group ($p = 0.38$). Estimated survival at 2 years was not different between the 2 groups (97% [95% CI 96 to 98] vs 97% [95% CI 97 to 98]; log-rank $p = 0.44$; Fig. 1). The frequency of type Ia endoleak identified on midterm follow-up among patients who underwent off-IFU EVAR was twice that of those whose EVAR was performed on IFU (2% vs 1%; $p = 0.03$) and the frequency of any postoperative reintervention was also significantly higher among off-IFU patients (6% vs 4%; $p = 0.002$). Those patients treated off IFU were estimated to have decreased freedom from reintervention at 2 years (93% [95% CI 91 to 94] vs 95% [95% CI 94 to 96]; log-rank $p = 0.02$, Fig. 2). Other graft-related complications were similar between the 2 groups and there was no difference in the freedom from AAA enlargement at 2 years (86% [95% CI 84 to 88] vs 87% [95% CI 86 to 88]; log-rank p = 0.27; Figure, Supplemental Digital Content 3, http://links.lww.com/JACS/A282).

Modeling midterm outcomes

Independent predictors for type Ia endoleak based on multivariable logistic regression are presented in Table 3. A multivariable logistic regression model correlating IFU status and type Ia endoleak adjusted for statistically and clinically significant demographic and anatomic variables in Table 1 resulted in an area under the receiver operating curve of 0.74 with a Hosmer-Lemeshow goodness of fit test of 9 ($p = 0.37$). Patients treated with off-IFU EVAR exhibited double the risk for developing a type Ia endoleak on follow-up (OR 1.84 [95% CI 1.23 to 2.76]; $p = 0.003$). Additional independent risk factors for type-1a endoleak included a longer procedure time, an infrarenal neck length of 10 to 15 mm vs more than 15 mm, an infrarenal neck angle of 45 to 60 degrees or 76 to 90 degrees compared with less than 45 degrees, and stent-graft from Graft 4 (all $p < 0.05$). Factors associated with lower risk of type-1a endoleak included female sex and an infrarenal neck diameter less than IFU (all $p < 0.05$).

Risk factors associated with AAA sac enlargement and reintervention within 2 years based on multivariable Cox modeling (Harrell's c = 0.61; Somers' D = 0.23) are presented in Tables 4 and 5. A single proximal aortic extension during index operation correlated with increased AAA sac enlargement within 2 years (hazard ratio [HR] 1.45 [95% CI 1.13 to 1.86]; $p = 0.003$) as did a longer procedure time (HR 1.12 [95% CI 1.04 to 1.20]; $p=0.002$). An infrarenal neck diameter smaller than IFU was associated with a lower risk for AAA sac enlargement (HR 0.67 [95% CI 0.47 to 0.97]; $p = 0.03$) as well as the use of a stent graft from Graft 2 (HR 0.58 [95% CI 0.45 to 0.76]; $p < 0.001$).

Cox modeling identifying factors associated with re-intervention (Harrel's c = 0.62, Somers' D = 0.25) within 2 years included off-IFU EVAR (HR 1.38 [95% CI 1.06 to 1.81]; $p = 0.02$), a history of infrarenal aortic surgery (HR 1.73 [95% CI 1.12 to 2.68]; $p = 0.01$), a longer procedure time (HR 1.22 [95% CI 1.12 to 1.33]; $p < 0.001$), and stent-graft from graft 3 (HR 1.81 [95% CI 1.38 to 2.38]; $p < 0.001$).

DISCUSSION

The current analysis provides several important observations in a large, national dataset. First, approximately one-quarter of elective infrarenal EVAR operations are performed with proximal neck IFU violations. Second, patients treated with off-IFU EVAR are at a significantly increased risk for type Ia endoleak and reintervention on midterm follow-up. Finally, there is no statistically significant difference in survival at 30 days or 2 years between off- and on-IFU infrarenal EVAR in the elective setting. These findings suggest that AAA patients with infrarenal necks not falling within the device's IFU have inferior outcomes compared with patients receiving on-IFU treatment; alternative procedures should be considered.

As vascular specialists continue to embrace minimally invasive therapies for aortic disease, shared decision-making with patients becomes ever more important, particularly on the topic of device failure. Our study demonstrates that roughly 25% of the elective EVAR procedures performed in the US violated the device manufacturer's proximal IFU and that these patients experienced an absolute 1% per year increase in device failure compared with similar patients treated on IFU. Amortized over a median life expectancy of 10 years in a patient treated for AAA in the US today,[12] this translates into a meaningful future workload and systemic cost. The differential durability and surveillance needs associated with successful open AAA surgery should also be presented before undertaking off-IFU EVAR, particularly for younger patients with low perioperative risk.[13,14] Numerous treatment options with different risks and benefits exist for infrarenal AAA and all should be shared with patients before performing EVAR in violation of IFU.

Instructions for use were developed by device manufacturers on the basis of preclinical engineering assessments and early-phase trials in order to maximize device performance and long-term durability as patients frequently have anatomy that may compromise graft apposition to the aortic wall, creating an inadequate seal.[9] The landmark trials demonstrating the efficacy of EVAR required adherence to IFU guidelines, hence outcomes following endovascular repair performed off IFU were not assessed.[15–18] Supposition as to the drivers behind broadening device application beyond IFU criteria runs the gamut, but our study echoes previous work showing a striking proportion of IFU nonadherence, ranging from 38% to 69% in previous literature.[7,9,19,20]

Hostile aortic neck and iliac anatomy have been implicated in negative clinical outcomes after EVAR.[21–26] While several studies did not identify a heightened risk of aneurysm-specific complications or mortality associated with off-IFU EVAR, there is evidence that IFU nonadherence increases the risk of aneurysm-related complications.[8,9] Our study found that proximal off-IFU EVAR was associated with a significant increased risk of type Ia endoleak by 84% and the risk for reintervention within 2 years by 38% compared with EVAR performed within IFU. A meta-analysis of 17 observational studies —predominantly single institution—that were published before 2017 found no difference in perioperative mortality, aneurysm rupture, technical failure, type I endoleak, or aneurysm-related reintervention, but did identify a signal for increased all-cause mortality associated with the use of off-IFU EVAR when compared with on-IFU EVAR.[6] A recent multicenter study revealed that any IFU violation with elective EVAR increased the risk for graft-related adverse events (ie a composite of reintervention, migration, endoleak, rupture, limb occlusion, sac enlargement, and aneurysm-related mortality).[9] Our study confirms these findings in a national dataset and further emphasizes that proximal neck violations, postulated to have a smaller impact on poor outcomes compared with iliac anatomic constraints,[27] nearly double the risk for a type Ia endoleak in a relatively short duration of follow-up compared with the timeframe the majority of off-IFU failures are expected to occur.

Vascular specialists have developed a broad array of techniques to treat complex abdominal aortic aneurysms with minimally invasive approaches.[28–30] Aneurysms involving the reno-visceral segment are frequently managed by fenestrated, branched, or physician-modified endografts, which may be off-the-shelf or customized to a patient's specific anatomy.[31] A recent analysis using VQI data demonstrated acceptable perioperative and long-term mortality as well as a low frequency of reinterventions associated with fenestrated EVAR or physician-modified endografts.[32] Although the use of these techniques is typically limited to high-volume centers, patients lacking the anatomy for standard EVAR due to IFU violations, particularly those who are unfit for open repair, may benefit from a complex endovascular repair. For younger patients with low perioperative risk and long life expectancy, the durability of an open repair should also be considered, especially in the setting of hostile neck anatomy.

Anecdotally, surgeons choose to perform an EVAR off IFU in order to avoid an invasive open repair with the attendant physiologic challenge to the patient. However, a study comparing endovascular and open repair in patients with anatomy outside of IFU demonstrated increased long-term survival and decreased aneurysm-related mortality in patients who underwent open repair compared with off-IFU EVAR.[8] Although EVAR confers an early survival advantage over open repair, this benefit is lost through time and a meta-analysis of the pivotal endovascular trials demonstrated that aneurysm-related mortality was higher among EVAR patients beyond 3 years.[33–35] These results call into question employing EVAR in patients with unsuitable anatomy given the superior durability of the open approach. Younger patients with low perioperative risk and a long life expectancy may particularly benefit from an open repair, especially in the setting of hostile neck anatomy.

Limitations of this study include the retrospective nature of this analysis in a self-reported database, which may lead to selection bias. Certain variables are underreported in VQI, resulting in missing data and limiting the scope of our analyses. Particularly, information on iliac artery anatomy was underreported and therefore not used to determine IFU status, limiting the analyses to proximal neck violations and likely explaining the low frequency of IFU violations compared to historic reports. Furthermore, a portion of the on-IFU group may have been misclassified given the potential for iliac IFU violations among these patients. Finally, patients without at least 1 follow-up visit were excluded from the present analysis, which may explain the higher-than-expected long-term survival experienced by patients in both groups.

CONCLUSIONS

A significant proportion of infrarenal elective EVAR patients are treated outside of proximal device IFU on a national level. While these patients did not have a statistically significant survival difference at 2 years, IFU violations were associated with an increased risk of type Ia endoleak and reintervention. Patients with infrarenal AAA with proximal anatomy outside of device IFU should be offered complex endovascular repair or open surgery rather than standard EVAR, particularly for younger patients with a longer life expectancy.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Abbreviations and Acronyms

AAA	abdominal aortic aneurysm
EVAR	endovascular aneurysm repair
IFU	instructions for use
VQI	Vascular Quality Initiative

REFERENCES

1. Dua A, Kuy S, Lee CJ, et al. Epidemiology of aortic aneurysm repair in the United States from 2000 to 2010. J Vasc Surg 2014;59:1512–1517. [PubMed: 24560865]
2. Paravastu SC, Jayarajasingam R, Cottam R, et al. Endovascular repair of abdominal aortic aneurysm. Cochrane Database Syst Rev 2014:Cd004178. [PubMed: 24453068]
3. Giles KA, Landon BE, Cotterill P, et al. Thirty-day mortality and late survival with reinterventions and readmissions after open and endovascular aortic aneurysm repair in Medicare beneficiaries. J Vasc Surg 2011;53:6–12,13.e1. [PubMed: 21030195]
4. Swerdlow NJ, Wu WW, Schermerhorn ML. Open and endovascular management of aortic aneurysms. Circ Res 2019;124:647–661. [PubMed: 30763206]
5. Ulug P, Sweeting MJ, von Allmen RS, et al. Morphological suitability for endovascular repair, non-intervention rates, and operative mortality in women and men assessed for intact abdominal aortic aneurysm repair: systematic reviews with meta-analysis. Lancet 2017;389:2482–2491. [PubMed: 28455148]
6. Antoniou GA, Juszczak MT, Nasr H, et al. Prognosis review and time-to-event data meta-analysis of endovascular aneurysm repair outside versus within instructions for use of aortic endograft devices. J Vasc Surg 2020;71:1415–1431.e15. [PubMed: 32057585]
7. Beckerman WE, Tadros RO, Faries PL, et al. No major difference in outcomes for endovascular aneurysm repair stent grafts placed outside of instructions for use. J Vasc Surg 2016;64:63–74.e2. [PubMed: 27017100]
8. Charbonneau P, Hongku K, Herman CR, et al. Long-term survival after endovascular and open repair in patients with anatomy outside instructions for use criteria for endovascular aneurysm repair. J Vasc Surg 2019;70:1823–1830. [PubMed: 31126766]
9. Herman CR, Charbonneau P, Hongku K, et al. Any nonadherence to instructions for use predicts graft-related adverse events in patients undergoing elective endovascular aneurysm repair. J Vasc Surg 2018;67:126–133. [PubMed: 28760581]
10. Walker J, Tucker LY, Goodney P, et al. Adherence to endovascular aortic aneurysm repair device instructions for use guidelines has no impact on outcomes. J Vasc Surg 2015;61:1151–1159. [PubMed: 25659454]
11. Society of Vascular Surgery Vascular Quality Initiative. SVS VQI Procedures Collected. Available at: https://www.vqi.org/about/vqi-procedures-collected/. Accessed April 8, 2021.
12. Lederle FA, Kyriakides TC, Stroupe KT, et al. Open versus endovascular repair of abdominal aortic aneurysm. N Engl J Med 2019;380:2126–2135. [PubMed: 31141634]
13. Chaikof EL, Dalman RL, Eskandari MK, et al. The Society for Vascular Surgery practice guidelines on the care of patients with an abdominal aortic aneurysm. J Vasc Surg 2018;67:2–77.e2. [PubMed: 29268916]
14. Spanos K, Nana P, Behrendt CA, et al. Management of abdominal aortic aneurysm disease: similarities and differences among cardiovascular guidelines and NICE guidance. J Endovasc Ther 2020;27:889–901. [PubMed: 32813590]
15. Becquemin JP, Pillet JC, Lescalie F, et al. A randomized controlled trial of endovascular aneurysm repair versus open surgery for abdominal aortic aneurysms in low- to moderate-risk patients. J Vasc Surg 2011;53:1167–1173.e1. [PubMed: 21276681]

16. Blankensteijn JD, de Jong SE, Prinssen M, et al. Two-year outcomes after conventional or endovascular repair of abdominal aortic aneurysms. N Engl J Med 2005;352:2398–2405. [PubMed: 15944424]
17. Greenhalgh RM, Brown LC, Kwong GP, et al. 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;364:843–848. [PubMed: 15351191]
18. Lederle FA, Freischlag JA, Kyriakides TC, et al. Long-term comparison of endovascular and open repair of abdominal aortic aneurysm. N Engl J Med 2012;367:1988–1997. [PubMed: 23171095]
19. Abbruzzese TA, Kwolek CJ, Brewster DC, et al. Outcomes following endovascular abdominal aortic aneurysm repair (EVAR): an anatomic and device-specific analysis. J Vasc Surg 2008;48:19–28. [PubMed: 18440182]
20. Baderkhan H, Goncalves FM, Oliveira NG, et al. Challenging anatomy predicts mortality and complications after endovascular treatment of ruptured abdominal aortic aneurysm. J Endovasc Ther 2016;23:919–927. [PubMed: 27385153]
21. AbuRahma AF, Yacoub M, Mousa AY, et al. Aortic neck anatomic features and predictors of outcomes in endovascular repair of abdominal aortic aneurysms following vs not following instructions for use. J Am Coll Surg 2016;222:579–589. [PubMed: 26905372]
22. Elkassaby M, Tawfick W, El-Deen H, et al. Predictors of major adverse anatomical events after elective endovascular abdominal aortic aneurysm repair at a tertiary referral center. Vasc Dis Manag 2020;17:E194–E202.
23. Oliveira NFG, Ultee K, van Rijn MJ, et al. Anatomic predictors for late mortality after standard endovascular aneurysm repair. J Vasc Surg 2019;69:1444–1451. [PubMed: 30477942]
24. Schanzer A, Greenberg RK, Hevelone N, et al. Predictors of abdominal aortic aneurysm sac enlargement after endovascular repair. Circulation 2011;123:2848–2855. [PubMed: 21478500]
25. Stather PW, Sayers RD, Cheah A, et al. Outcomes of endovascular aneurysm repair in patients with hostile neck anatomy. Eur J Vasc Endovasc Surg 2012;44:556–561. [PubMed: 23122183]
26. Taudorf M, Jensen LP, Vogt KC, et al. Endograft limb occlusion in EVAR: iliac tortuosity quantified by three different indices on the basis of preoperative CTA. Eur J Vasc Endovasc Surg 2014;48:527–533. [PubMed: 24878235]
27. Powell JT, Sweeting MJ, Ulug P, et al. Editor's choice - re-interventions after repair of ruptured abdominal aortic aneurysm: a report from the IMPROVE randomised trial. Eur J Vasc Endovasc Surg 2018;55:625–632. [PubMed: 29503083]
28. Georgiadis GS, van Herwaarden JA, Antoniou GA, et al. Systematic review of off-the-shelf or physician-modified fenestrated and branched endografts. J Endovasc Ther 2016;23:98–109. [PubMed: 26496957]
29. Oderich GS, Greenberg RK, Farber M, et al. ; Zenith Fenestrated Study Investigators. Results of the United States multicenter prospective study evaluating the Zenith fenestrated endovascular graft for treatment of juxtarenal abdominal aortic aneurysms. J Vasc Surg 2014;60:1420–8.e1. [PubMed: 25195145]
30. Starnes BW, Heneghan RE, Tatum B. Midterm results from a physician-sponsored investigational device exemption clinical trial evaluating physician-modified endovascular grafts for the treatment of juxtarenal aortic aneurysms. J Vasc Surg 2017;65:294–302. [PubMed: 27687323]
31. Suckow BD, Goodney PP, Columbo JA, et al. National trends in open surgical, endovascular, and branched-fenestrated endovascular aortic aneurysm repair in Medicare patients. J Vasc Surg 2018;67:1690–1697.e1. [PubMed: 29290495]
32. O'Donnell TFX, Patel VI, Deery SE, et al. The state of complex endovascular abdominal aortic aneurysm repairs in the Vascular Quality Initiative. J Vasc Surg 2019;70:369–380. [PubMed: 30718110]
33. Powell JT, Sweeting MJ, Ulug P, et al. Meta-analysis of individual-patient data from EVAR-1, DREAM, OVER and ACE trials comparing outcomes of endovascular or open repair for abdominal aortic aneurysm over 5 years. Br J Surg 2017;104:166–178. [PubMed: 28160528]
34. Patel R, Sweeting MJ, Powell JT, et al. Endovascular versus open repair of abdominal aortic aneurysm in 15-years' follow-up of the UK endovascular aneurysm repair trial 1 (EVAR trial 1): a randomised controlled trial. Lancet 2016;388:2366–2374. [PubMed: 27743617]

35. Schermerhorn ML, Buck DB, O'Malley AJ, et al. Long-term outcomes of abdominal aortic aneurysm in the Medicare population. N Engl J Med 2015;373:328–338. [PubMed: 26200979]

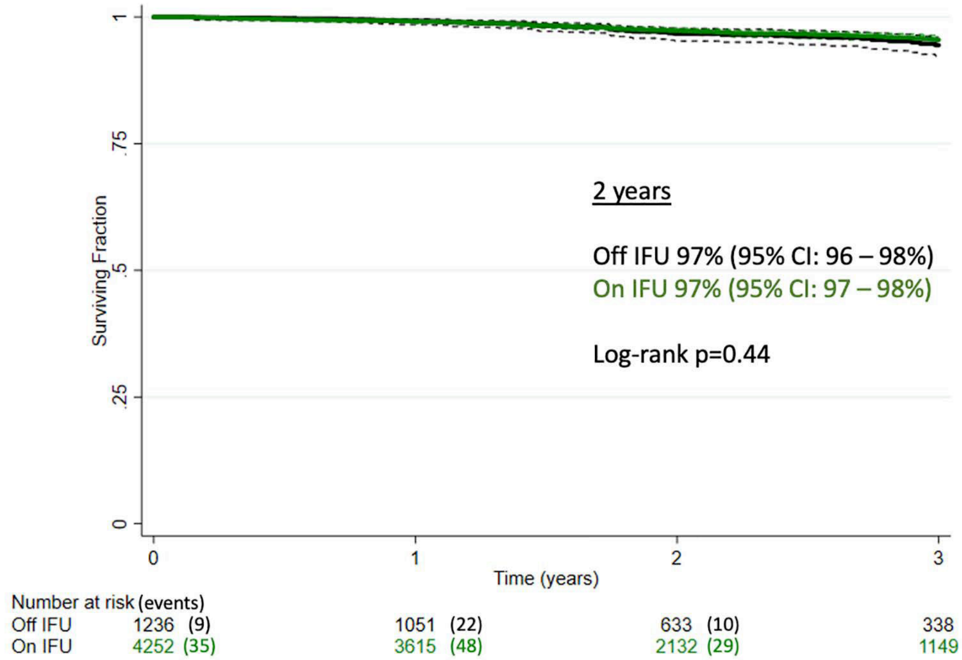

Figure 1.

Kaplan-Meier curve for overall survival for patients treated on- vs off-IFU endovascular aortic repair.

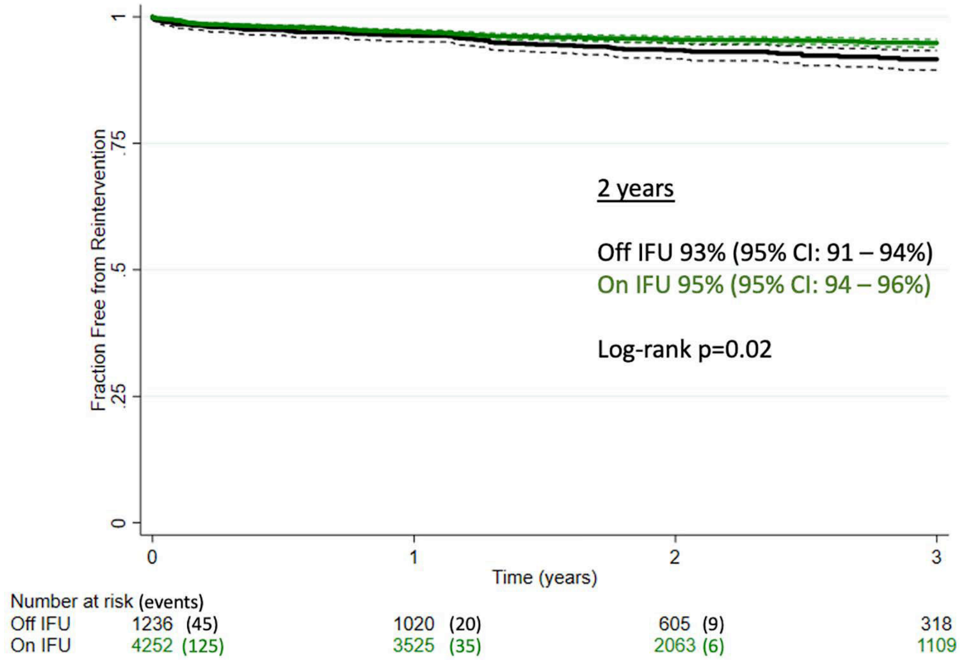

Figure 2.

Kaplan-Meier curve for reintervention for patients treated with on- vs off-IFU endovascular aortic repair.

Table 1.

Baseline Characteristics for Patients with Infrarenal Abdominal Aortic Aneurysm Treated with On- vs Off-IFU Endovascular Aneurysm Repair

Variable	Off-IFU	On-IFU	p Value*
Repair category			
Total, n	1,236 (23)	4,252 (77)	
Center volume, patients/y, median (IQR)	18 (10–28)	19 (11–30)	0.002
Demographic			
Age, y, median (IQR)	74 (68–80)	73 (67–79)	0.001
Female sex, n (%)	336 (27)	639 (15)	<0.001
White race, n (%)	1,118 (90)	3,935 (93)	0.03
Hispanic ethnicity, n (%)	30 (2)	114 (3)	0.62
Hypertension, n (%)	1,029 (83)	3,475 (82)	0.22
Diabetes, n (%)	210 (17)	795 (19)	0.17
Tobacco abuse, n (%)	1,036 (84)	3,724 (88)	0.001
CAD, n (%)	339 (27)	1,222 (29)	0.37
CHF, n (%)	137 (11)	448 (11)	0.58
COPD, n (%)	410 (33)	1,261 (30)	0.02
Preoperative statin, n (%)	896 (72)	3,103 (73)	0.76
BMI, kg/m^2, mean (SD)	28 (5.6)	29 (5.7)	<0.001
eGFR, mL/min/1.73 m^2, mean (SD)	68 (23)	69 (21.7)	0.14
Preoperative characteristic			
Unfit for open repair, n (%)	223 (18)	609 (14)	0.001
Preoperative Hgb, g/dL, mean (SD)	13.6 (1.78)	13.8 (1.82)	<0.001
Preoperative anticoagulation, n (%)	142 (11)	523 (12)	0.44
Previous infrarenal aortic surgery, n (%)	87 (7)	191 (4)	<0.001
Previous vascular treatment, n (%)			
Carotid	69 (6)	162 (4)	0.006
Lower extremity	75 (6)	285 (7)	0.43
Major amputation	12 (1)	16 (<0.01)	0.01

Variable	Off-IFU	On-IFU	p Value*
AAA max diameter, mm, mean (SD)	56 (11.5)	55 (10.2)	0.07
Neck length, mm, mean (SD)	21 (13)	28 (12)	<0.001
Neck diameter, mm, mean (SD)	23 (8)	24 (3)	<0.001
Infrarenal neck angle, n (%)			<0.001
<45 degrees	768 (62)	3,697 (87)	
45–60 degrees	145 (12)	534 (13)	
61–75 degrees	139 (11)	9 (<0.01)	
76–90 degrees	106 (9)	12 (<0.01)	
>91 degrees	78 (6)	0 (<0.01)	
Procedural characteristics and outcomes			
Procedure time, h, median (IQR)	2.0 (1.5–2.7)	1.8 (1.4–2.5)	<0.001
Fluoroscopy time, min, median (IQR)	20 (14–31)	18 (13–26)	<0.001
Anesthesia, n (%)			0.92
Local	73 (6)	239 (6)	
Epidural	45 (4)	158 (4)	
GETA	1,118 (90)	3,855 (91)	
Contrast, mL, mean (SD)	100 (61.6)	89 (50.9)	<0.001
Crystalloid, mL, mean (SD)	1,712 (909)	1,622 (816)	0.001
EBL, mL, median (IQR),	100 (50–200)	100 (50–200)	0.14
Percent oversize, median (IQR)	21 (11–30)	17 (12–30)	<0.001
Graft configuration, n (%)			<0.001
Bifurcated	1,144 (93)	4,059 (95)	
Uni-iliac	71 (6)	166 (4)	
Aorto-aortic	21 (2)	27 (1)	
Graft, n (%)			<0.001
1	188 (15)	657 (15)	
2	536 (43)	1,587 (35)	
3	290 (23)	1,320 (31)	
4	47 (4)	174 (4)	

Variable	Off-IFU	On-IFU	p Value*
5	166 (13)	563 (13)	
6	8 (1)	39 (1)	
7	1 (<0.01)	12 (<0.01)	
Proximal aortic extension, n (%)			<0.001
1 cuff	232 (19)	616 (15)	
2 cuffs	38 (3)	43 (1)	
3 cuffs	2 (<0.01)	8 (<0.01)	
Renal artery covered, n (%)	20 (2)	28 (1)	0.001
Covered renal treated	13 (65)	17 (61)	0.76
Intraoperative conversion to open, n (%)	1 (<0.01)	1 (<0.01)	0.35
Endoleak on completion, n (%)			
Any	283 (23)	1,051 (25)	0.19
Type 1a	75 (6)	110 (3)	<0.001
Type 1b	13 (1)	29 (1)	0.19
Type 3	2 (<0.01)	12 (<0.01)	0.46

IQR is presented as (Q1–Q3).

*Calculated using a χ^2 test for categorical variables, 2-tailed Student's *t*-test for approximately normally distributed continuous variables, and a Mann-Whitney test for other continuous variables.

AAA, abdominal aortic aneurysm; CAD, coronary artery disease; CHF, congestive heart failure; EBL, estimated blood loss; eGFR, estimated glomerular filtration rate; GETA, general endotracheal anesthesia; IFU, instructions for use; IQR, interquartile range.

Table 2.

Midterm Outcomes for Patients with Infrarenal Abdominal Aneurysm Repair Treated with On- vs Off-IFU Endovascular Aneurysm Repair

Variable	Off-IFU	On-IFU	p Value*
Repair category			
Follow-up visits, median (IQR)	1 (1–1)	1 (1–2)	<0.001
Follow-up time, d, mean (SD)	401 (167)	406 (171)	0.38
Endoleak during follow-up, n (%)			
Any	218 (18)	732 (17)	0.76
New	151 (12)	514 (12)	0.92
Persistent	67 (5)	218 (5)	0.69
Resol ved	214 (17)	828 (20)	0.08
Type 1a	19 (2)	35 (1)	0.03
New	15 (1)	29 (1)	0.07
Persistent	4 (0)	6 (0)	0.19
Resolved	70 (6)	105 (3)	<0.001
Type 1b	13 (1)	30 (1)	0.22
New	11 (1)	29 (1)	0.45
Persistent	2 (0)	1 (0)	0.07
Resolved	11 (1)	28 (1)	0.39
Type 3	5 (0)	10 (0)	0.32
New	5 (0)	10 (0)	0.31
Persistent	0 (0)	0 (0)	—
Resolved	2 (0)	12 (0)	0.46
Any reintervention, n (%)	79 (6)	182 (4)	0.002
Days to reintervention, median (IQR)	232 (49–498)	220 (45–419)	0.45
Indication for reintervention, n (%)			
Sac enlargement	11 (14)	33 (18)	0.40
Endoleak			
Any	37 (47)	94 (52)	0.48

Variable	Off-IFU	On-IFU	p Value*
Type Ia	13 (16)	18 (10)	0.05
Type Ib	6 (16)	23 (24)	0.31
>Type III	2 (5)	6 (6)	0.83
Migration	4 (5)	3 (2)	0.12
Occlusion	11 (14)	43 (24)	0.08
Stenosis	9 (11)	18 (10)	0.71
Infection	6 (8)	5 (3)	0.07
Rupture	1 (1)	5 (3)	0.46
Other	7 (9)	18 (10)	0.80
AAA maximum diameter, mm, mean (SD)	51 (14)	50 (12)	0.24
AAA maximum diameter decrease, %, median (IQR)	7 (0–17)	7 (0–17)	0.96
Patients with AAA enlargement, n (%)	284 (23)	933 (22)	0.43

IQR is presented as (Q1–Q3).

*Calculated using a χ^2 test for categorical variables, 2-tailed Student's *t*-test for approximately normally distributed continuous variables, and a Mann-Whitney test for other continuous variables.

AAA, abdominal aortic aneurysm; IFU, instructions for use; IQR, interquartile range.

Table 3.

Multivariable Logistic Regression Model Assessing Factors Associated with Type Ia Endoleak for Patients with Infrarenal Abdominal Aortic Aneurysm Treated with On- vs Off-IFU Endovascular Aneurysm Repair (n = 5,424)

Variable	Odds ratio	95% CI	p Value
Off IFU	1.84	1.23–2.76	0.003
Graft 4	2.18	1.37–3.46	0.001
Contrast, mL	1.01	1.00–1.01	<0.001
Procedure time, h	1.20	1.08–1.33	0.001
Infrarenal neck length			
>15 mm	1 (Ref)	—	—
10–15 mm	1.55	1.08–2.22	0.02
<10 mm	1.13	0.62–2.07	0.68
Neck diameter			
IFU	1 (Ref)	—	—
Smaller than IFU	0.44	0.23–0.84	0.01
Neck angle			
<45 degrees	1 (Ref)	—	—
45–60 degrees	1.91	1.33–2.75	<0.001
61–75 degrees	0.85	0.40–1.81	0.68
76–90 degrees	2.05	1.08–3.92	0.03
>90 degrees	1.49	0.62–3.56	0.37
Female sex	0.42	0.31–0.56	<0.001

Adjusted for log of the average yearly center volume, physician, sex, previous infrarenal aortic surgery, procedure time, fluoroscopy time, contrast volume, infrarenal neck length category, infrarenal neck diameter category, infrarenal neck angle and company. AUROC = 0.74, Hosmer-Lemeshow goodness of fit = 9; p = 0.37.

IFU, instructions for use.

Table 4.

Cox Proportional Hazards Model Assessing Factors Associated with Abdominal Aortic Aneurysm Sac Enlargement for Patients with Infrarenal Abdominal Aortic Aneurysm Treated with On- vs Off-IFU Endovascular Aneurysm Repair

Abdominal aortic aneurysm sac enlargement*	Hazard ratio	95% CI	p Value
Off IFU	1.19	0.96–1.47	0.11
Proximal cuff x1	1.45	1.13–1.86	0.003
Physician	1.00	1.00–1.00	0.001
Procedure time, h	1.12	1.04–1.20	0.002
Neck diameter			
IFU	1 (Ref)	—	—
Smaller than IFU	0.67	0.47–0.97	0.03
Graft 2	0.58	0.45–0.76	<0.001

Harrell's C = 0.61; Somers' D = 0.23. Adjusted for log of the average yearly center volume, physician, sex, tobacco abuse, COPD, previous infrarenal aortic surgery, procedure time, fluoroscopy time, contrast volume, infrarenal neck length category, infrarenal neck diameter category, infrarenal neck angle, company, endoleak type 1a, 1b, or 3 on completion, and proximal aortic cuffs.

* n = 5,471.

IFU, instructions for use.

Table 5.

Cox Proportional Hazards Model Assessing Factors Associated with Reintervention for Patients with Infrarenal Abdominal Aortic Aneurysm Treated with On- vs Off-IFU Endovascular Aneurysm Repair

Reintervention*	**Hazard ratio**	**95% CI**	**p Value**
Off IFU	1.38	1.06–1.81	0.02
Graft 6	2.23	0.91–5.48	0.08
Graft 3	1.81	1.38–2.38	<0.001
Previous infrarenal aortic surgery	1.73	1.12–2.68	0.01
Physician	1.00	1.00–1.00	0.004
Procedure time, h	1.22	1.12–1.33	<0.001

Harrell's C = 0.62; Somers' D = 0.25. Adjusted for log of the average yearly center volume, physician, sex, previous infrarenal aortic surgery, procedure time, fluoroscopy time, contrast volume, infrarenal neck length category, infrarenal neck diameter category, infrarenal neck angle, and company.

*n = 5,477.

IFU, instructions for use.