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Endovascular vs. Open Repair of Intact Descending Thoracic Aortic Aneurysms

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Abstract

Background: For the management of descending thoracic aortic aneurysms, recent evidence has suggested that outcomes of open surgical repair may surpass thoracic endovascular aortic repair (TEVAR) as early as 2 years.

Objectives: To evaluate the comparative effectiveness of TEVAR and open surgical repair in the treatment of intact descending thoracic aortic aneurysms.

Methods: Using the Medicare database, a retrospective study employing regression discontinuity design and propensity score matching was performed on patients with intact descending thoracic aortic aneurysms who underwent TEVAR or open surgical repair between 1999 and 2010 with follow-up through 2014. Survival was assessed with restricted mean survival time. Perioperative mortality was assessed with logistic regression. Reintervention was evaluated as a secondary outcome.

Results: Matching created comparable groups with 1,235 open surgical repair patients matched to 2,470 TEVAR patients. The odds of perioperative mortality were greater for open surgical repair: high-volume-center, OR 1.97 (95% CI 1.53 to 2.61); low-volume-center, OR 3.62 (95% CI 2.88 to 4.51). The restricted mean survival time difference favored TEVAR at 9-years, −209.2 days (95% CI −298.7 to −119.7 days; $p < 0.001$) for open surgical repair. Risk of reintervention was lower for open surgical repair, HR 0.40 (95% CI 0.34 to 0.60; $p < 0.001$).

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Conclusion: Open surgical repair was associated with increased odds of early postoperative mortality but reduced late hazard of death. Despite the late advantage of open repair, mean survival was superior for TEVAR. TEVAR should be considered first line for repair of intact descending thoracic aortic aneurysms in Medicare beneficiaries.

Condensed Abstract:

For the management of descending thoracic aortic aneurysms, open surgical repair and thoracic endovascular aortic repair (TEVAR) are options for therapy. We performed a retrospective study of patients with intact descending thoracic aortic aneurysms who underwent TEVAR or open surgical repair using a regression discontinuity design and propensity score matching in the Medicare database. There were 1,235 open surgical repair patients matched to 2,470 TEVAR patients. Odds of perioperative mortality were greater for open surgical repair; restricted mean survival time difference favored TEVAR. TEVAR should be considered first line for repair of intact descending thoracic aortic aneurysms in Medicare beneficiaries.

Keywords

Descending Aorta; Endovascular Surgery; Thoracic Aorta; Aortic Surgery; TEVAR

Introduction

In 1994, thoracic endovascular aortic repair (TEVAR) was introduced as an alternative to open surgical repair for treatment of descending thoracic aortic aneurysms (1). Following U.S. Food and Drug Administration (FDA) approval in 2005, the use of TEVAR has been increasing (2,3). This shift in practice has come as a result of excellent perioperative outcomes with TEVAR reported in small prospective non-randomized trials.(4,5) However, larger studies using either the Medicare database or meta-analytic methods have suggested that the survival advantage of TEVAR may be lost by 2 years with open surgical repair potentially having superior midterm outcomes (6,7). Reflecting the uncertainty of the comparative effectiveness, professional guidelines fail to offer guidance outside of technical infeasibility for TEVAR or poor candidacy for open surgical repair (8-10).

Efforts to elucidate either short or long term results using data from the Nationwide Inpatient Sample and the Medicare database have been limited due to the reliance on imprecise diagnostic and procedural codes from the *International Classification of Diseases, Ninth Revision* (ICD-9).(2,3,6,11) ICD-9 codes fail to distinguish among ascending, arch, and descending thoracic aortic aneurysms. Aneurysms in each location are treated with a different approach, and expected survival varies.(12-16) As such, the inability to distinguish among these disease processes may introduce substantial bias. We undertook the current study using *Current Procedural Terminology* (CPT) codes, which are able to distinguish among operations on different segments of the thoracic aorta, to compare mid-term outcomes of TEVAR and open surgical repair in Medicare beneficiaries with intact un-dissected descending thoracic aortic aneurysm.

Methods

Data Collection and Study Population

We retrospectively reviewed data from the Centers for Medicare & Medicaid Services administrative database from 1999-2010 with follow-up through 2014. Patient demographics and survival data were obtained from the Beneficiary Summary file; ICD-9 diagnosis codes pertaining to the descending thoracic aorta were obtained from the MedPAR file; comorbidity data were obtained from the Chronic Conditions Summary file; and surgeon-billed CPT codes pertaining to prior and current surgical procedures were obtained from the Carrier file. We limited our analysis to patients with a CPT code specific to open surgical repair of the descending thoracic aorta (33875) and CPT (33880 and 33881) or ICD-9 (39.73) codes for endovascular repair of the thoracic aorta (17,18).

Patients who underwent concomitant procedures (e.g. ascending aorta or transverse arch repairs, repairs of the thoracoabdominal aorta, endovascular or open repair of the abdominal aorta, and cardiac surgical procedures) were excluded. Patients with aortic dissection, ruptured thoracic aortic aneurysm, trauma, or aorto-enteric fistulae were also excluded (Online Figure 2). We determined each patient's underlying aortic pathology with an algorithm (described previously (14)) that incorporated ICD-9 diagnosis codes recorded during prior and current hospitalizations.

Regression Discontinuity Design

An analysis using propensity score alone was not appropriate due to the lack of anatomic information—a factor influencing treatment selection (19)—in this administrative database. As such, we used the abrupt change in practice pattern following the introduction of TEVAR in a regression discontinuity design (20). The introduction of TEVAR as a commercially viable alternative to open surgical repair occurred with FDA approval in late 2005. Patients undergoing operations prior to FDA approval were encouraged towards open surgical repair with 100% compliance. Following FDA approval of TEVAR, virtually all patients were compliant with treatment encouragement toward TEVAR, 94.4% compliance (Online Figure 1). Our analysis then proceeded as an “intent to treat”; patients in the second half of the study period undergoing open surgical repair were treated similarly to non-compliers in a randomized trial and analyzed as part of the TEVAR group. This approach was used due to the inability to identify patients who were anatomically ineligible for TEVAR in the early phase of the study.

Covariate balancing

The introduction of TEVAR as an alternative to open surgical repair increased the pool of patients clinically eligible for aortic repair resulting in an imbalance in baseline covariates (Table 1). Observed differences in baseline covariates between patients encouraged toward open surgical repair (prior to FDA approval of TEVAR) and patients encouraged toward TEVAR (following FDA approval of TEVAR) were balanced using propensity score matching (21,22). A non-parsimonious logistic regression model was used to estimate the probability of encouragement to open surgical repair. Optimal matching was then performed with 2 TEVAR patients matched to each open surgical repair patient in order to estimate the average treatment effect for open surgical repair (22). Balance between covariates was assessed between the two groups before and after matching using the standardized differences approach; a standardized mean difference of <0.1 was considered to be ideal and <0.2 was considered to be acceptable (23,24).

Center volume

Center volume was defined as the volume of open surgical repairs performed prior to the introduction of TEVAR. This allowed for an estimate of operative experience that was less biased by the rapid expansion of treating centers resulting from the introduction of TEVAR. Centers in the 90th percentile of operative volume during this time (>10 open surgical repairs among Medicare beneficiaries in the early period under study) were defined *a priori* to be high-volume centers.

Study End Points

The primary endpoint was all-cause mortality. Vital status and date of death were validated with National Death Index data from 1999-2008 or, if these data were unavailable, an internal Medicare determination of death; agreement between these sources exceeded 99% (25). The secondary endpoint was reintervention (either open or endovascular) on the descending thoracic aorta using the following CPT (open: 33875; endovascular: 33880, 33881, 33883, 33884, and 33886) and ICD-9 codes (endovascular: 39.73). Follow up was available through 2014.

Statistical Analysis

Survival was evaluated using the Kaplan-Meier method and restricted mean survival time (RMST); RMST is the population average for survival during the specified follow-up period.(26) In order to account for non-proportionality of hazards, we used a time-partitioning technique separating perioperative mortality (≤180 days) from the late hazard (>180 days); early mortality was assessed using logistic regression with a robust variance estimator. Hospital volume was tested as an effect modifier for open surgical repair, and 95% confidence intervals were estimated with 500 bootstrap replicates.(14) Late mortality was then assessed with Cox proportional hazards regression in a landmark analysis, i.e. contingent 180-day survival. Aortic reintervention was evaluated with death as a competing risk using the Fine-Gray method (27). Two-sided p-value <0.05 was considered to be statistically significant. Analyses were conducted with R-3.4.1 (R Foundation, *Vienna, Austria*).

Sensitivity Analyses

To control for institution-level variation, we performed a sensitivity analysis restricted to the 349 hospitals present in both the early and late periods. The effect of a secular trend was evaluated by comparing open repair in the early and late periods using inverse probability weighting (28). To account for surgical volume as an effect modifier for open surgical repair, additional analyses were performed comparing open surgical repair at a high-volume center to TEVAR and separately open surgical repair at a low-volume center to TEVAR. Finally, the population was restricted to the time period from 2004 to 2006, i.e. the year before and the year after FDA approval, in order to examine the effect of TEVAR in closer detail around the time of the discontinuity (20). For additional details on our statistical analyses, please refer to the Online Appendix, Methods section.

Results

We identified 16,955 Medicare patients with specific codes for endovascular (n=11,411) or open surgical repair (n=5,544) of the descending thoracic aorta. Patients who underwent concomitant cardiac surgical procedures, underwent branch vessel revascularization other than carotid-to-subclavian bypass, and those who had aortic dissection, trauma, or aorto-enteric fistula were excluded (Online Figure 2). Prior to matching, the cohort consisted of 1,235 open surgical repair and 4,580 TEVAR patients. There was a decrease in the frequency of open surgical repair following the introduction of TEVAR and a substantial increase in the overall frequency of descending thoracic aortic aneurysms treated in Medicare beneficiaries (Online Figure 1).

Prior to matching, TEVAR patients tended to be older and have a greater burden of chronic diseases than open surgical repair patients; TEVAR patients were also less likely to be treated at a high-volume open surgical center (Table 1). Our matching algorithm successfully matched each open surgical repair patient with two TEVAR patients; balance was achieved across all available covariates (Table 1, Online Table 1, and Online Figure 3A). There were 183 patients non-compliant with treatment encouragement to TEVAR; non-compliance was not observed among open surgical repair patients. Unmatched patients in the TEVAR group (n = 2,110) were older and had more chronic comorbidities than patients who were successfully matched (Online Table 2 and Online Figure 3B).

Mortality

The median duration of follow-up in the matched group was 5.6 years (interquartile range [IQR]: 0.7 to 10.0 years) for open surgical repair patients and 4.7 years (IQR: 2.5 to 6.4 years) for TEVAR patients. Mortality was significantly lower among TEVAR patients than open surgical repair patients, Log-Rank Test p<0.001 (Figure 1). There was clear evidence that the hazard of open surgical repair varied over time with an early phase of increased risk and a later phase with lower risk of death compared with TEVAR. Mortality at 180-days was greater among open surgical repair patients, 23.9% (21.5% to 26.2%) compared with TEVAR, 10.4% (9.2% to 11.6%), and the interaction between open surgical repair and hospital volume was significant, odds ratio (OR) for high-volume open surgical centers with respect to TEVAR: 1.97 (95% confidence interval [CI] 1.53 to 2.61) and for low-volume open surgical centers: 3.62 (95% CI 2.88 to 4.51), p-value for interaction = 0.002 (Table 2). Conversely, late hazard of death was reduced in the open surgical repair group, Hazard Ratio (HR) 0.86 (95% CI 0.77 to 0.95; p = 0.004) (Online Figure 4). The difference in RMST was −209.2 days (95% CI −298.7 to −119.7 days; p <0.001) revealing a substantial survival disadvantage with open surgical repair compared with TEVAR at 9-years, Table 2 and Online Figure 5.

Among those patients treated after the introduction of TEVAR, patients who were matched had significantly lower comorbidity burden (Online Table 2) and lower mortality during follow-up than patients who went unmatched, HR 0.70 (95% CI 0.65 to 0.76; p <0.001) (Online Figure 6). Sensitivity analyses demonstrated that institutional differences (Online Tables 3 and 4, Online Figure 7), time period (Online Tables 5 and 6, Online Figure 8), adjustments for center volume (Online Tables 7-10, Online Figures 9 and 10), and limiting the study period to the time immediately surrounding the discontinuity (Online Tables 11 and 12, Online Figure 11) did not affect the inference from the main analysis. Although there was a reduction in perioperative mortality for open surgical repair in the second half of the study period (OR 0.70, 95% CI 0.49 to 0.99, p = 0.04), there was no difference in risk of midterm death (HR 1.21, 0.97 to 1.51, p = 0.1). For additional details on the sensitivity analyses, please see the Online Appendix.

Reintervention

Within the matched regression discontinuity analysis, there were 293 first-time reinterventions on the descending thoracic aorta, and 90.7% (266/293) of these reinterventions were performed endovascularly. Moreover, there was substantial risk associated with reintervention. Among open surgical repair patients, reintervention (28.4% open, 71.6% TEVAR) was associated with a 23.5% risk of 180-day mortality. Among TEVAR patients, reintervention (1.9% open, 98.1% TEVAR) was associated with a 19.3% risk of 180-day mortality. Open surgical repair patients experienced a significantly lower likelihood of reintervention at 9-years, 5.3% (95% CI 3.9% to 6.6%) compared with TEVAR, 10.1% (95% CI 8.8% to 11.5%), HR 0.45 (95% CI 0.34 to 0.60; p <0.001) (Figure 2).

Discussion

The use of open surgical repair for intact un-dissected descending thoracic aortic aneurysms declined precipitously after the introduction of TEVAR despite an increase in the overall frequency of aneurysms repaired. To determine the comparative effectiveness of these competing strategies, we performed a propensity matched analysis within a regression discontinuity design. Open surgical repair was associated with higher early mortality than TEVAR; however, the late hazard of death and risk of reintervention were lower among patients who underwent open surgical repair (Central Illustration). Despite the potential improved durability of open surgical repair, the initial mortality advantage of TEVAR over open surgical repair persisted until 9-years post-operatively resulting in a significant survival benefit associated with TEVAR.

Differences in Survival between TEVAR and Open Surgical Repair

Hospital volume significantly affected perioperative outcome, one of the major driving forces for the difference between TEVAR and open surgical repair. Regionalization of care by limiting open surgical repair to a group of high-volume and high-performing centers should be considered given the superior outcomes seen at centers of excellence. Referral to an aortic center may further improve the likelihood of appropriate treatment selection after weighing the risks and benefits of each approach. Furthermore, the declining use of open surgical repair for patients with descending thoracic aortic aneurysms suggests that concentrating care at a select group of regional centers with adequate volume to maintain an active program will become increasingly more important as the number of centers performing enough operations to be considered high-volume dwindles.

Beyond the perioperative period, the hazard of death associated with TEVAR was higher than after open surgical repair, and this may have been due to a difference in durability of repair. In the Medtronic thoracic endovascular registry (MOTHER) and the 5-year follow-up of the VALOR trial, there was ongoing risk for aortic death beyond the perioperative period in patients treated with TEVAR; midterm reintervention due to endoleak, aneurysm growth, or migration occurred in 14-16% of patients with descending thoracic aortic aneurysms (29,30). Reintervention likely underestimates the risk of graft or endograft failure and disease progression as some patients may die with occult failure while others may be turned down for reintervention on account of technical or clinical considerations. These findings point to the absolute necessity of close follow up for TEVAR patients to detect late complications. The increased hazard for reoperation is an intrinsic limitation of TEVAR given the inability to occlude feeding intercostal vessels, ensure adequate distal and proximal seal in the face of disease progression within adjacent segments, and avoid leaks between stent grafts with or without migration of components.

Despite potential differences in durability with a concomitant increase in late hazard of death for TEVAR, the mean survival of patients out to 9 years was >6 months greater for patients receiving TEVAR than for open surgical repair. Most of this survival difference was accumulated in the early phase; as such, whether a survival difference would exist favoring open surgical repair in a younger cohort of patients with lower perioperative risk and greater potential long-term survival is unknown. Inclusion of younger patients—mean age 51 for open surgical repair—in the meta-analysis by Cheng et al. may explain the lower perioperative mortality and the earlier convergence of survival curves (7). An important area for future investigation, using a clinical database, may be to develop a predictive algorithm for risk stratifying patients undergoing open surgical repair with the lowest risk patients potentially benefiting the most from open surgical repair. Unfortunately, a comparable study in younger patients would not be possible using the Nationwide Inpatient Sample or the Society of Thoracic Surgeons-Adult Cardiac Surgery Database due to the absence of long-term follow-up in those databases. Additionally, state-level databases, which rely on ICD-9 codes, would also be inadequate for such an analysis.

Differences between TEVAR and EVAR

The existing literature on TEVAR versus open surgical repair suggests that the survival benefit of TEVAR is lost as early as 2 years but possibly as late as 5 years.(6,7,31) These results appeared to parallel the modest overall survival benefit attributable to endovascular aortic repair for abdominal aortic aneurysms, which achieved parity at approximately 3-to-4 years with an RMST difference reported by Schermerhorn et al. of only 5.6 days at 8-years (32-34). This is in stark contrast with the substantial survival advantage discovered in our study with an RMST difference of 209.2 days and convergence of survival curves at 9-years. Despite the reduced durability compared with open surgical repair seen in our analysis, endovascular repair may be better suited to the descending thoracic aorta than the abdominal aorta as there more frequently exist long segments of aorta that may act as appropriate landing zones capable of resisting disease progression for a longer time post-procedure. This may explain the difference in comparative effectiveness of endovascular and open repair between the descending thoracic aorta and the abdominal aorta.

Unmatched patients

A substantial minority of patients treated in the latter half of the study period were excluded as a result of our matching algorithm. Reflective of the greater age and comorbidity burden, the survival of these patients was significantly worse after TEVAR than those patients who were able to be matched mirroring results observed by our group previously.(35) Due to the reduced risk of perioperative morbidity and mortality, endovascular treatment has been offered to patients who were traditionally considered to be poor surgical candidates contributing—in part—to the greater frequency of descending thoracic aortic aneurysms treated. Excluding these patients improves the internal validity of our study due to the lack of eligibility for open surgical repair in this subset of patients. Given the high risk and poor survival of this cohort, TEVAR appears to be appropriate if any intervention is to be undertaken at all.

Limitations

This investigation was limited by its retrospective design in an administrative database and while causal inference techniques were used to evaluate the comparative effectiveness of the two competing treatments, our study falls short of a randomized trial in its ability to posit a causal effect. Moreover, unmeasured confounding in the form of unobserved clinical variables, such as frailty or anatomic features, may be present. Regression discontinuity with an "intention-to-treat" design was used to limit many of these potential sources of bias, which have not been addressed in prior investigations. Propensity score matching was used to address imbalances in baseline covariates given the increase in the chronic comorbidities observed in the TEVAR period. Following matching, all covariates were balanced adequately. With respect to outcome measures, our use of an administrative database left us unable to determine whether endoleaks were present following TEVAR, i.e. that the thoracic endograft was functioning appropriately during followup. Finally, the perioperative outcome for open surgical repair at high-volume aortic centers in a contemporary cohort may be better than we observed in the Medicare database thus altering the risk-benefit tradeoff to be less weighted towards TEVAR. While we performed sensitivity analyses to evaluate the potential effect of hospital-level characteristics and secular trends on our inference, the true effect in a contemporary cohort could not be estimated.

Conclusion

Among Medicare beneficiaries, patients undergoing open surgical repair for intact un-dissected descending thoracic aortic aneurysm had greater odds of early death than TEVAR patients. Despite the lower risk of reintervention and lower late hazard of death, open surgical repair only achieved parity with TEVAR after 9-years resulting in a substantial survival benefit associated with TEVAR The superior survival observed in patients undergoing TEVAR as compared to open surgical repair suggests that TEVAR ought to be considered first-line among Medicare beneficiaries with open surgical repair restricted to high-volume centers and patients with low risk of perioperative mortality.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

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Abbreviations:

CI	Confidence Interval
CPT	Current Procedural Terminology
EVAR	Endovascular Aortic Repair
FDA	U.S. Food and Drug Administration
HR	Hazard Ratio
ICD-9	International Classification of Diseases, Ninth Revision
OR	Odds Ratio
RMST	Restricted Mean Survival Time
TEVAR	Thoracic Endovascular Aortic Repair

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CLINICAL PERSPECTIVES

Competency in Medical Knowledge:

Among Medicare beneficiaries with intact descending thoracic aortic aneurysms, endovascular stent-grafting by an experienced operator is the preferred method of thoracic aortic repair.

Translational Outlook:

Further studies are needed to define the optimum timing of intervention for patients with thoracic aortic aneurysms undergoing elective endovascular therapy.

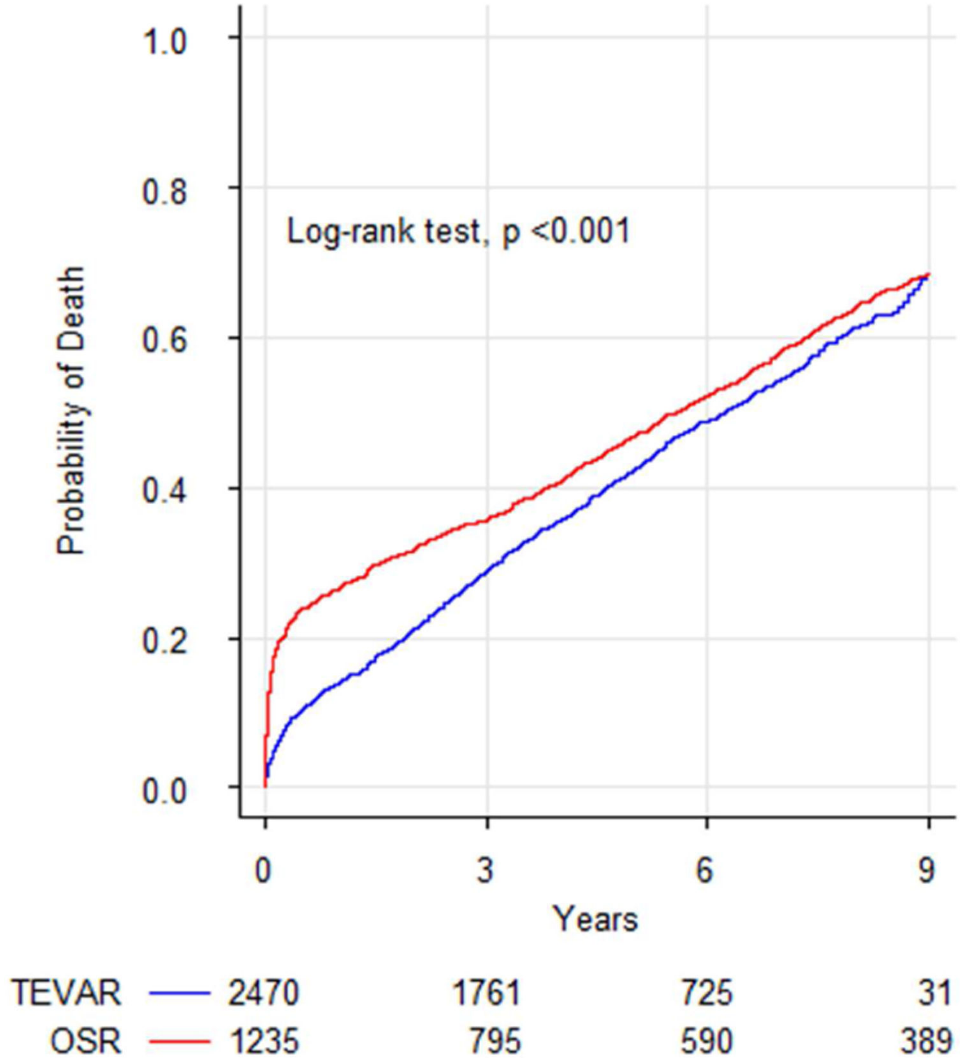


Figure 1. Cumulative incidence of death with TEVAR and open surgical repair.

The difference in mortality between open surgical repair and TEVAR was statistically significant by the log-rank test, $p < 0.001$. Additionally, the difference in restricted mean survival time was significant: −209.2 days (95% CI −298.7 to −119.7 days; $p < 0.001$) suggesting that there was a substantial survival disadvantage with open surgical repair.

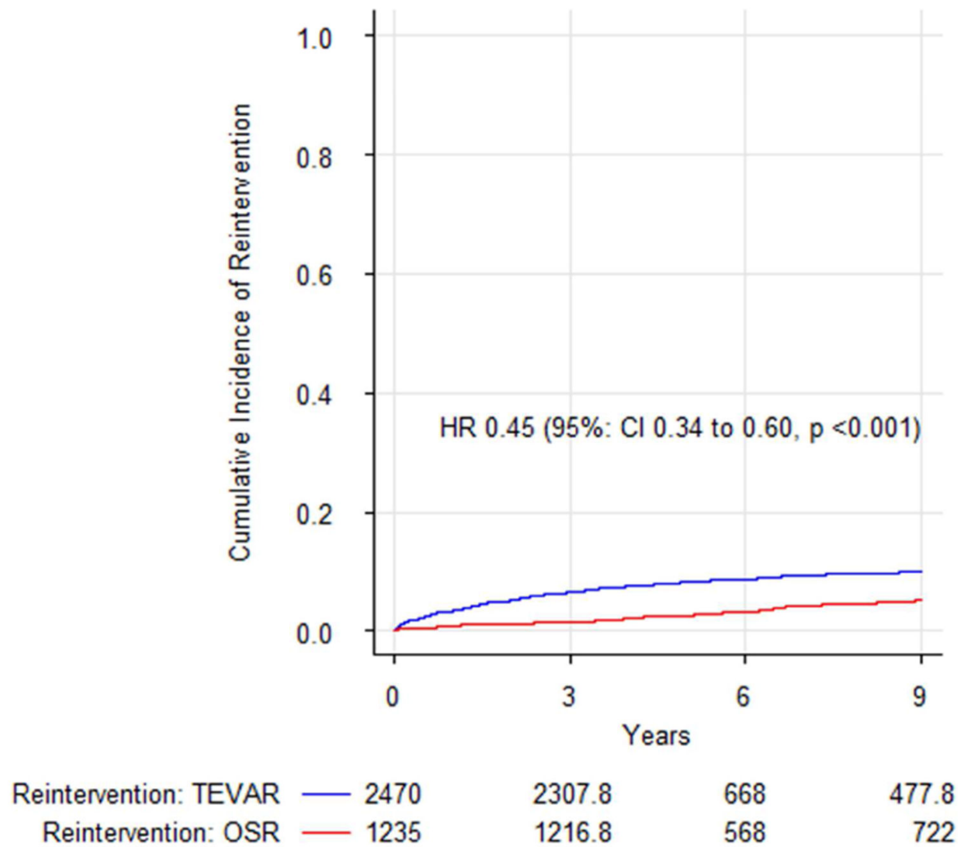
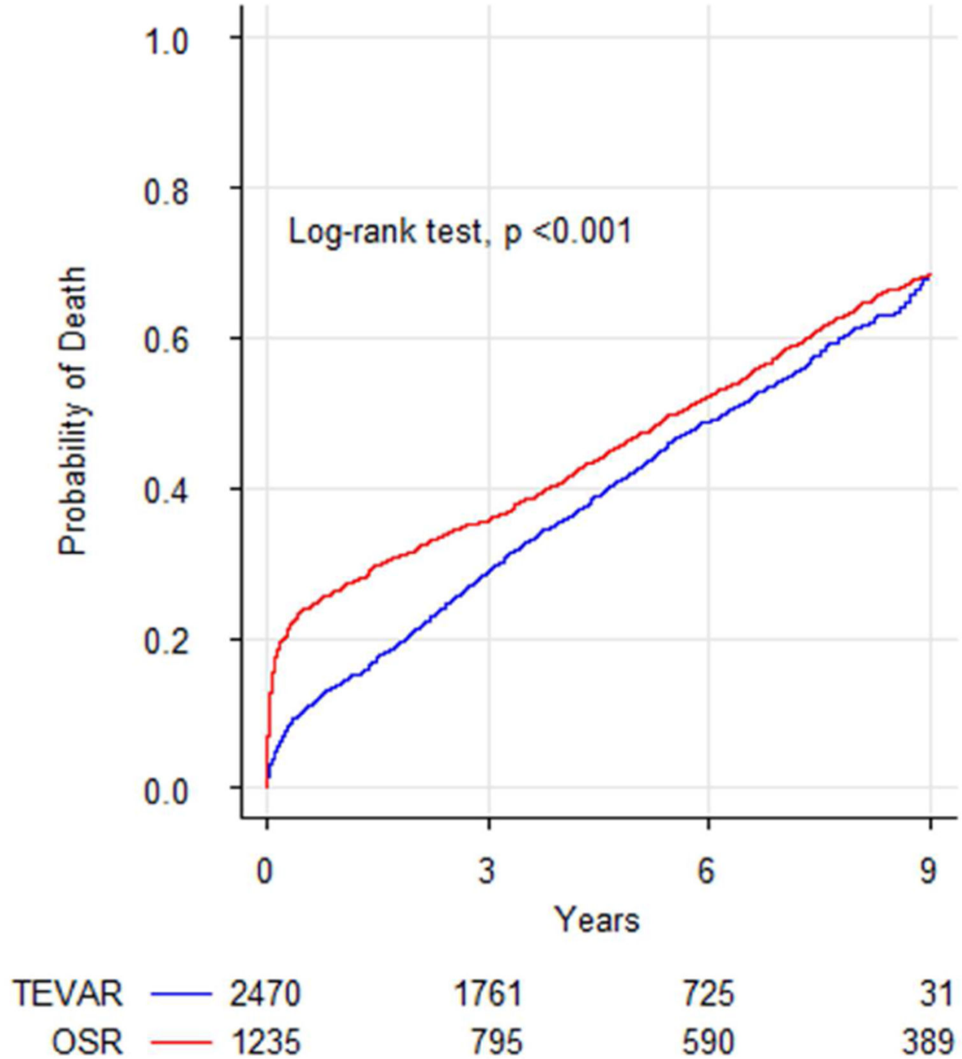


Figure 2. Cumulative incidence of reintervention for TEVAR and open surgical repair.

The subdistribution hazard for reintervention was lower for open surgical repair as compared with TEVAR in the matched groups.



Central Illustration: Thoracic Endovascular Aortic Repair Vs. Open Surgical Repair: Cumulative Incidence of Mortality.

The cumulative incidence of mortality was greater with open surgical repair due to increased risk of periprocedural death. Due to higher late hazard for mortality, the mortality benefit of TEVAR was eventually lost at approximately 9 years.

Table 1.

Demographic and clinical variables.

	Before Matching			After Matching		
	TEVAR n = 4580	**Open Surgical Repair n = 1235**	**SMD**	**TEVAR n = 2470**	**Open Surgical Repair n = 1235**	**SMD**
Operative Year, median [IQR]	2008 [2007, 2009]	2002 [2000, 2003]	3.783	2008 [2007, 2009]	2002 [2000, 2003]	3.742
Age, mean (sd)	74.99 (8.32)	72.88 (7.52)	0.265	72.97 (8.36)	72.88 (7.52)	0.011
Age (categorical)			0.357			0.066
Age <70	1155 (25.2)	362 (29.3)		763 (30.9)	362 (29.3)	
Age ≥ 70 and <80	2127 (46.4)	700 (56.7)		1322 (53.5)	700 (56.7)	
Age ≥ 80	1298 (28.3)	173 (14.0)		385 (15.6)	173 (14.0)	
Male Gender	2571 (56.1)	710 (57.5)	0.027	1423 (57.6)	710 (57.5)	0.002
Race			0.151			0.007
Asian	90 (2.0)	25 (2.0)		49 (2.0)	25 (2.0)	
Black	453 (9.9)	105 (8.5)		211 (8.5)	105 (8.5)	
Hispanic	69 (1.5)	20 (1.6)		38 (1.5)	20 (1.6)	
North American Native	19 (0.4)	6 (0.5)		12 (0.5)	6 (0.5)	
Other	70 (1.5)	3 (0.2)		6 (0.2)	3 (0.2)	
Unknown	9 (0.2)	1 (0.1)		2 (0.1)	1 (0.1)	
White	3870 (84.5)	1075 (87.0)		2152 (87.1)	1075 (87.0)	
Alzheimer Dementia	341 (7.4)	49 (4.0)	0.150	105 (4.3)	49 (4.0)	0.014
Stroke or TIA	852 (18.6)	136 (11.0)	0.215	298 (12.1)	136 (11.0)	0.033
Depression	1101 (24.0)	163 (13.2)	0.281	378 (15.3)	163 (13.2)	0.060
Myocardial Infarction	280 (6.1)	36 (2.9)	0.155	91 (3.7)	36 (2.9)	0.043
Atrial Fibrillation	814 (17.8)	159 (12.9)	0.136	354 (14.3)	159 (12.9)	0.043
Congestive Heart Failure	1765 (38.5)	343 (27.8)	0.230	746 (30.2)	343 (27.8)	0.054
Ischemic Heart Disease	3200 (69.9)	895 (72.5)	0.057	1705 (69.0)	895 (72.5)	0.076
Hypertension	3859 (84.3)	982 (79.5)	0.123	1948 (78.9)	982 (79.5)	0.016
Hyperlipidemia	3371 (73.6)	624 (50.5)	0.490	1484 (60.1)	624 (50.5)	0.193
Chronic Obstructive Pulmonary Disease	2196 (47.9)	482 (39.0)	0.181	1047 (42.4)	482 (39.0)	0.068
Asthma	615 (13.4)	113 (9.1)	0.135	244 (9.9)	113 (9.1)	0.025
Chronic Kidney Disease	1425 (31.1)	170 (13.8)	0.425	385 (15.6)	170 (13.8)	0.052

	Before Matching			After Matching		
	TEVAR n = 4580	Open Surgical Repair n = 1235	SMD	TEVAR n = 2470	Open Surgical Repair n = 1235	SMD
Benign Prostatic Hyperplasia	974 (21.3)	163 (13.2)	0.215	374 (15.1)	163 (13.2)	0.056
End-stage Renal Disease	154 (3.4)	27 (2.2)	0.072	61 (2.5)	27 (2.2)	0.019
Diabetes	1358 (29.7)	240 (19.4)	0.239	531 (21.5)	240 (19.4)	0.051
Hypothyroidism	676 (14.8)	110 (8.9)	0.182	248 (10.0)	110 (8.9)	0.039
Glaucoma	734 (16.0)	144 (11.7)	0.127	291 (11.8)	144 (11.7)	0.004
Cataract	2557 (55.8)	481 (38.9)	0.343	1054 (42.7)	481 (38.9)	0.076
Hip Fracture	105 (2.3)	22 (1.8)	0.036	49 (2.0)	22 (1.8)	0.015
Osteoporosis	665 (14.5)	93 (7.5)	0.225	198 (8.0)	93 (7.5)	0.018
Arthritis	1926 (42.1)	313 (25.3)	0.359	704 (28.5)	313 (25.3)	0.071
Anemia	2445 (53.4)	448 (36.3)	0.349	983 (39.8)	448 (36.3)	0.073
Breast Cancer	162 (3.5)	30 (2.4)	0.065	66 (2.7)	30 (2.4)	0.015
Colorectal Cancer	178 (3.9)	22 (1.8)	0.127	58 (2.3)	22 (1.8)	0.040
Prostate Cancer	319 (7.0)	72 (5.8)	0.046	152 (6.2)	72 (5.8)	0.014
Lung Cancer	165 (3.6)	34 (2.8)	0.048	66 (2.7)	34 (2.8)	0.005
Endometrial Cancer	28 (0.6)	4 (0.3)	0.042	7 (0.3)	4 (0.3)	0.007
Prior Aortic Valve Replacement	93 (2.0)	27 (2.2)	0.011	55 (2.2)	27 (2.2)	0.003
Prior Aortic Root Replacement	38 (0.8)	6 (0.5)	0.043	25 (1.0)	6 (0.5)	0.061
Prior Ascending Aortic Replacement	88 (1.9)	44 (3.6)	0.101	48 (1.9)	44 (3.6)	0.099
Prior Aortic Arch Replacement	77 (1.7)	23 (1.9)	0.014	49 (2.0)	23 (1.9)	0.009
Prior Mitral Valve Surgery	13 (0.3)	6 (0.5)	0.033	5 (0.2)	6 (0.5)	0.048
Prior Tricuspid Valve Surgery	2 (0.0)	0 (0.0)	0.030	0 (0.0)	0 (0.0)	<0.001
Prior Coronary Artery Bypass Grafting	367 (8.0)	103 (8.3)	0.012	184 (7.4)	103 (8.3)	0.033
Prior Ventricular Assist Device	3 (0.1)	0 (0.0)	0.036	0 (0.0)	0 (0.0)	<0.001
Prior Transplant	1 (0.0)	0 (0.0)	0.021	1 (0.0)	0 (0.0)	0.028
Subclavian Bypass	171 (3.7)	8 (0.6)	0.212	89 (3.6)	8 (0.6)	0.206
High-Volume Open Surgical Center	1650 (36.0)	614 (49.7)	0.279	894 (36.2)	614 (49.7)	0.276
Urgency			0.112			0.043
Emergency	592 (12.9)	193 (15.6)		369 (14.9)	193 (15.6)	
Urgent	551 (12.0)	177 (14.3)		325 (13.2)	177 (14.3)	
Elective	3429 (74.9)	863 (69.9)		1771 (71.7)	863 (69.9)	

	Before Matching			After Matching		
	TEVAR n = 4580	**Open Surgical Repair n = 1235**	**SMD**	**TEVAR n = 2470**	**Open Surgical Repair n = 1235**	**SMD**
Unknown	8 (0.2)	2 (0.2)		5 (0.2)	2 (0.2)	

Table 2.

Early death, late death, and mid-term survival

	Open Surgical Repair	TEVAR	p
Mortality at 180 days, % (95% CI)	23.9% (21.5% to 26.2%)	10.4% (9.2% to 11.6%)	
Low-volume open surgical center, % (95% CI)	29.7% (25.6 to 33.6%)		
High-volume open surgical center, % (95% CI)	18.5% (15.4% to 21.6%)		
Odds of early mortality (<=180 days)			
Low-volume open surgical center, OR (95% CI)	3.62 (2.88 to 4.51)	Reference	
High-volume open surgical center, OR (95% CI)	1.97 (1.53 to 2.61)	Reference	
Mortality at 5-years	46.7% (43.9% to 49.4%)	42.2% (40.2% to 44.1%)	
Mortality at 9-years	68.4% (65.7% to 70.9%)	68.6% (64.3% to 72.3%)	
Hazard of late death (>180 days), HR (95% CI)	0.86 (0.77 to 0.95)	Reference	0.004
Restricted mean survival time, days	−209.2 (−298.7 to −119.7)	Reference	p <0.001
Restricted mean survival time ratio	0.90 (0.86 to 0.94)	Reference	p <0.001
Restricted mean time lost	1.17 (1.09 to 1.25)	Reference	p <0.001