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Contemporary trends in practice patterns and clinical outcomes of thoracic endovascular aortic repair for nontraumatic thoracic aortic disease in the Vascular Quality Initiative

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ABSTRACT

Introduction: The purpose of this analysis was to document longitudinal changes in thoracic endovascular aortic repair practice patterns and clinical outcomes, using data from the Vascular Quality Initiative.
Methods: All patients who underwent elective or nonelective thoracic endovascular aortic repair from 2015 to 2023 were reviewed ($N = 23,532$). The primary outcomes were in-hospital mortality and long-term survival. Secondary outcomes included in-hospital major complications and postoperative spinal cord ischemia. Procedures were classified into 3 time periods: early (2015–2017), middle (2018–2020), and late (2021–2023).
Results: Among elective procedures, a significant trend toward an increased proportion of dissection and penetrating aortic ulcer/intramural hematoma indications being treated over time was noted. Overall crude incidence of postoperative complications decreased significantly (25% vs 23% vs 21%; $P < .001$). In risk-adjusted analysis, incidence of any in-hospital complication declined for elective procedures, as well as nonelective cases (odds ratio, 0.93–0.96; 95% confidence interval, 0.92–0.98; $P = .002$). In particular, risk of spinal cord ischemia decreased after elective procedures (odds ratio, 0.96; 0.92–0.99; $P = .03$) but showed no change for nonelective cases despite an overall decrease in preoperative spinal drain use (41% vs 33% vs 23%; $P < .001$). Overall, unadjusted rates of in-hospital death did not vary significantly between time periods (5.8% vs 5.4% vs 5.4%; $P = .45$). However, in risk-adjusted analysis, in-hospital mortality risk decreased longitudinally after elective surgery (odds ratio, 0.94; 0.9–0.98; $P = .001$) but not for nonelective cases ($P = .13$). Cox regression analysis showed improved long-term survival for elective cases (hazard ratio, 0.96; 0.94–0.99; $P = .02$) but no change for nonelective procedures.
Conclusion: This analysis offers contemporary insights into thoracic endovascular aortic repair practice patterns and clinical outcomes, providing valuable benchmarking information for stakeholders focused on enhancing care delivery for this complex patient population.

Introduction

Since the seminal description of thoracic of endovascular aortic repair (TEVAR) by Dake and colleagues in 1994, the past 3 decades have been characterized by dramatic shifts in the management and outcomes for patients with thoracic aortic disease. Because of the significant reduction in its associated perioperative morbidity, TEVAR has largely supplanted open aortic reconstruction and is

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now considered first-line therapy for the spectrum of thoracic aortic pathology in both the elective and nonelective settings. Indeed, many patients who would otherwise be deemed inoperable are now effectively offered endovascular repair in the elective, as well as in the nonelective setting.[1] Despite the evolution of TEVAR, several controversies persist, including optimal patient selection and spinal drain use, as well as concerns surrounding durability, and establishment of benchmarks for postoperative outcome quality improvement assessment.

Moreover, several associated technical controversies surrounding TEVAR care remain topics of debate, such as the role of left subclavian artery revascularization and false lumen management, among others.[2] Not surprisingly, as a result of the heterogeneous indications for TEVAR, reported outcomes vary significantly. To date, it remains unclear how the adoption of TEVAR over time has translated into disease-specific trends in outcomes. Moreover, few studies have examined the evolution of center experience over time to better understand how this relates to TEVAR outcomes. Therefore, the purpose of this analysis was to document longitudinal changes in TEVAR practice patterns and clinical outcomes over time, using real-world data from a large multicenter national quality improvement registry.

Methods

Study design and data sources

A retrospective analysis was performed using the Society for Vascular Surgery-Vascular Quality Initiative (SVS-VQI). Additional information about the SVS-VQI, including registry details and variable definitions, can be requested at https://www.vqi.org. Data were reported using STrengthening the Reporting of OBservational studies in Epidemiology (STROBE) guidelines. The SVS-VQI Research Advisory Committee approved the request for deidentified data from all participating centers. The University of Florida Institutional Review Board approved this study and deemed it exempt from patient consent.

All patients who underwent elective or nonelective TEVAR from 2015 to 2023 were reviewed ($N = 25{,}838$). Patients missing data on indication other than aneurysm, dissection, or penetrating aortic ulcer/intramural hematoma (PAU/IMH) were excluded ($n = 96$), as were patients presenting with trauma or aortic thrombus ($n = 2{,}210$), leaving a cohort of 23,532 TEVAR procedures for analysis. The SVS-VQI TEVAR registry does not capture procedures performed for infected aneurysm (ie, excludes primary or secondary infectious presentations, as well as aortoesophageal, aortobronchial, aortogastric fistula) or pseudoaneurysm. Similarly, the registry does not capture revisions of previous open or endovascular thoracic aortic and thoracoabdominal repairs in the same anatomical region. Patients undergoing simultaneous ascending aortic replacement, coronary artery bypass, and/or valve repair with a TEVAR are included in the registry. A routine audit of all relevant billing data is performed with registry participation to verify 100% case capture for each participating center.

Study endpoints and statistical analysis

The primary goal of the analysis was to determine time-driven variations in practice patterns, including indications for repair, patient risk profiles, and clinical outcomes. The primary outcomes were in-hospital mortality and long-term survival. Secondary outcomes included rate of preoperative spinal drain use, in-hospital major complications, and postoperative spinal cord ischemia (SCI). For univariate presentation, procedures were classified into 3 time periods: early period (2015–2017, $n = 6{,}316$), middle period (2018–2020, $n = 8{,}294$) and late period (2021–2023, $n = 8{,}922$). For risk-adjusted multivariable analysis, year of surgery was treated as a continuous variable. For survival outcomes, procedures performed 2021–2023 were excluded because of a lack of sufficient follow-up.

Spearman correlations and Mann–Whitney *U* tests were used to make univariate comparisons between time period and continuous and categorical factors, respectively. Mixed-effects logistic and Cox regression models were used to assess the effect of surgery year when adjusting for indication, patient age, sex, ethnicity, race, transfer status, primary insurer, body mass index, rural-urban commuting area code, living status (at home, yes or no), functional status (fully functional, yes or no), cerebrovascular disease, coronary artery disease, congestive heart failure, diabetes mellitus, elevated creatinine (>1.7 mg/dL) or on dialysis, hypertension, smoking status, previous coronary artery bypass graft, previous percutaneous coronary intervention, carotid endarterectomy/carotid angioplasty with stenting, any type of previous aneurysm repair, infrainguinal bypass, peripheral vascular intervention, any type of previous aortic surgery, major limb amputation, abnormal stress test, hemoglobin class (>12|10–12| < 10 g/dL), preoperative aspirin, statin, P2Y-antagonist, beta-blocker, angiotensin-converting enzyme inhibitor, ejection fraction (<50%, yes or no), quartile of aortic diameter, distal extent of disease and American Society for Anesthesiologists class >3. All models included a random factor to account for the clustering of observations on hospital. These models were performed separately for elective and nonelective admissions. In a secondary analysis, separate models were performed for each of 3 main indications (degenerative aneurysm, aortic dissection, and "aortic syndrome," which included penetrating aortic ulcer/intramural hematoma indications), and separately for elective and nonelective admissions within each indication type.

Because VQI hospital membership changed over the study time period (centers contributing cases to TEVAR increased from 99 to 153 between 2015 and 2023), a preliminary analysis was performed to assess the potential for changing membership to bias any observed effects of time. Results for all outcomes were compared between a "core" group of 65 centers that were members of VQI continuously from 2015 to 2023 and 142 other hospitals that joined and/or left VQI after 2015. Risk-adjusted models, as described previously, showed no evidence that trends across time in any outcome were associated with changing VQI membership. All analyses were performed using the R statistical software package (version 4.0.3; The R Foundation for Statistical Computing, Vienna, Austria).

Results

Baseline characteristics and procedural details

Although the volume of TEVAR procedures entered into the VQI increased, largely as the result of expanding registry membership, the median number of procedures performed at each center per year did not change significantly (median, 13; estimated increase, 0.35 procedures/year, $P = .09$). For elective procedures (75% of cohort), a significant trend was noted toward a relative increase in the proportion of dissections and PAU/IMH indications over time, but this trend was not observed for nonelective procedures (Figure 1).

Among the 23,532 TEVAR procedures performed during the study period, 27%, 35%, and 38% were conducted in the early, middle, and late periods, respectively. Although the absolute differences in patient factors across treatment eras were small, there were some notable changes in characteristics over time. For example, although patient age was relatively unchanged, an increasing proportion of non-White patients and asymptomatic presentations were managed contemporaneously. Also, patients treated in the most recent time period were more likely to have

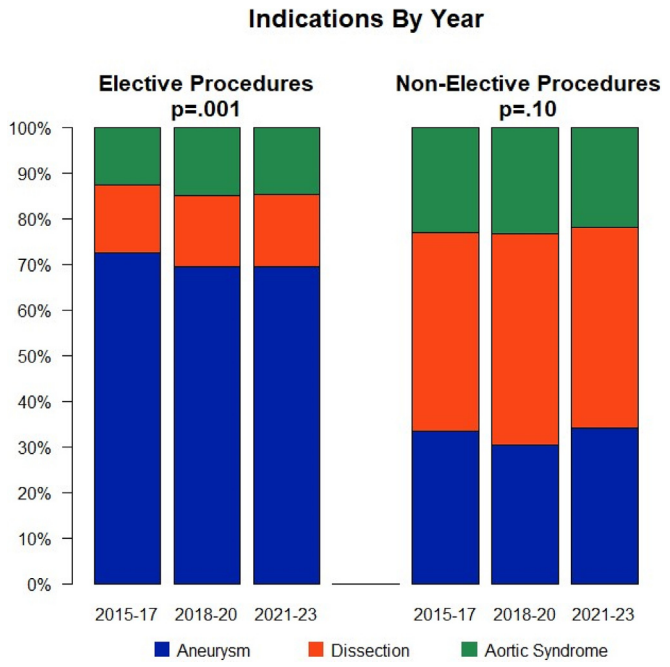

Figure 1. Percentage distribution of elective and nonelective thoracic of endovascular aortic repair over time, stratified by indication.

nonprivate insurance and greater prevalence of comorbidities (Table I). However, a significant reduction in the proportion of patients with normal functional status was observed over time (68% vs 63% vs 59%; $P < .001$), as well as a concomitant increase in the proportion of patients with previous aortic surgery (23% vs 28% vs 30%, $P < .001$). Despite a significant increase in the preoperative use of statins, their overall prescription rate was less than in two-thirds of the entire study cohort (59% vs 64% vs 66%, $P < .001$).

The use of IVUS remained stable over time, but technical success rates appeared to decrease over time (Table II). In addition, significant trends were evident toward a reduction in mean intravenous contrast use, intraoperative crystalloid administration, and estimated blood loss. In contrast, a concomitant increase was noted in fluoroscopy time (median 25 vs 26 vs 29 minutes; $P < .0001$), although mean total procedure time remained stable 189 vs 179 vs 184 minutes; $P = .185$). Use of custom-modified devices rose sharply over time (23% vs 28% vs 33%; $P < .0001$), whereas use of spinal drains declined dramatically (41−23%, $P < .0001$, Table III).

Postoperative complications and in-hospital mortality

The overall incidence of postoperative complications decreased significantly over time (25% vs 23% vs 21%; $P < .001$) (Table III). In analysis by indication, this trend held for both elective and nonelective aneurysm patients undergoing TEVAR (*P*-for-trend: .002 and .003, respectively) (Figure 2, *A*), and for elective, but not nonelective, PAU/IMH presentations (*P*-for-trend: 0.08 and 0.2, respectively) (Figure 2, *B*). However, the rate of complications remained unchanged over time for elective and nonelective dissection-related indications (*P*-for-trend: 0.2 and 0.5, respectively) (Figure 2, *C*). Rates of preoperative spinal drain use decreased significantly over time (41% vs 33% vs 23%, $P < .001$), although unadjusted rates of postoperative SCI remained stable (~3.5%, *P*-for-trend = .4).

In risk-adjusted analysis, incidence of any in-hospital complication declined for elective procedures (odds ratio [OR] multiplied by 0.94 each year [0.92−0.95], $P < .001$) as well as nonelective cases (OR multiplied by 0.96 each year [0.94−0.98], $P = .002$). After stratification by indication, these findings remained consistent for aneurysms (elective: OR multiplied by 0.93 each year [0.91−0.95], $P < .001$; nonelective: OR multiplied by 0.92 each year [0.88−0.96], $P = .0002$), but the association could not be confirmed for dissections (elective: $P = .06$; nonelective: $P = .41$) or for aortic syndromes (PAU/IMH: elective: $P = .13$; nonelective: $P = .45$). In particular, SCI rates decreased over time for elective procedures (OR multiplied by 0.96 each year [0.92−0.99], $P = .03$) but showed no change for nonelective cases ($P = .85$). Also, in this case, the association remained most consistent for aneurysms but not for dissections or aortic syndromes.

Overall, crude rates of in-hospital death did not vary significantly between the 3 periods being considered (5.8% vs 5.4% vs 5.4%; $P = .451$; Table III). However, after stratification by timing of repair, in hospital mortality decreased significantly for elective procedures, whereas the trend was not significant for nonelective ones (Figure 3, *A*). Significant differences in such observations could, however, be noted among different indications; in fact, although the observations were consistent for aneurysm cases (Figure 3, *B*), no significant trend could be observed for dissection cases (Figure 3, *C*) and a trend toward a significant reduction for nonelective aortic syndromes (Figure 3, *D*). In risk-adjusted analysis, the odds for in-hospital mortality decreased over time for elective surgery (OR multiplied by 0.94 each year [0.90−0.98], $P = .001$) but not for nonelective cases ($P = .13$). After stratification by indication for intervention, these findings remained consistent for aneurysms (elective: OR multiplied by 0.92 each year [0.88−0.96], $P = .0002$; nonelective: $P = .480$), but were not replicated for dissections (elective: $P = .71$; nonelective: $P = .42$) and aortic syndromes (elective: $P = .72$; nonelective: $P = .09$).

Long-term survival

Because VQI follow-up data were lacking for recent years, the dataset was truncated after 2020 for all analyses of long-term postoperative mortality. Kaplan-Meier analysis showed no changes in long-term survival for elective cases (long-rank $P = .30$), but worsening survival over time for nonelective cases (long-rank $P = .04$, Figure 4, *A*). However, risk-adjusted Cox regression analysis showed improved long-term survival for elective cases (hazard ratio multiplied by 0.96/yr, 95% confidence interval, 0.94−0.99, $P = .02$), but no change for nonelective procedures ($P = .15$). When stratified by indication (Figure 4, *B-D*), Kaplan-Meier survival was significantly worse over time for nonelective aneurysm (long-rank $P = .003$) and elective dissection (log-rank $P = .05$) but was not significantly different for other indication/admission status combinations. Furthermore, in risk-adjusted analysis, only the result for nonelective aneurysm remained significant (hazard ratio multiplied by 1.1/yr, 95% confidence interval, 1.02−1.12, $P = .008$).

Sensitivity analysis

As an additional sensitivity analysis, we divided the cohort into procedures treated at hospitals at or above the 90th percentile of average annual case volume (≥46 TEVAR procedures/year; $n = 21$ hospitals and $n = 10{,}455$ procedures in our data) and those with lower volume (<46 procedures/year; $n = 186$ hospitals and $n = 13{,}077$ procedures). We then performed all analyses for all outcomes and compared the overall effects of year of surgery with results observed in each subcohort. For all outcomes in all subsets of the data, results for the subcohorts closely mirrored the overall results, suggesting no evidence that trends are confined to high- or low-volume centers (Supplementary Table S1).

Table I
Baseline demographics and comorbidities of the study cohort, stratified by year of index intervention

Feature, *n* (%)	Overall (*N* = 25,742)	2015–2017 (*n* = 6,912; 27%)	2018–2020 (*n* = 9,039; 35%)	2021–2023 (*n* = 9,791; 38%)	*P* value
Annual center case volume	18.7 (20.2); 11 [6,25] (1,96)	21.3 (22.0); 14 [6,27] (1,96)	20.2 (20.8); 13 [6,26] (1,96)	21.1 (21.0); 14 [6,27] (1,96)	NA
Age, yr	67.3 (14.3)	67.3 (14.3)	67.2 (14.1)	67.2 (14.4)	.498
Male	16,896 (65.7)	4,476 (64.8)	5,948 (65.8)	6,472 (66.1)	.164
Hispanic	1,416 (5.5)	337 (4.9)	500 (5.5)	579 (6.0)	.012
Race					
White	18,152 (70.6)	5,037 (72.9)	6,417 (71.0)	6,698 (68.5)	<.0001
Black	4,624 (18.0)	1,199 (17.4)	1,668 (18.5)	1,757 (18.0)	
Other	2,943 (11.4)	671 (9.7)	947 (10.5)	1,325 (13.5)	
Admission status					
Elective	17,956 (69.8)	4,753 (68.8)	6,402 (70.9)	6,801 (69.5)	.003
Urgent	4,370 (17.0)	1,261 (18.3)	1,474 (16.3)	1,635 (16.7)	
Emergent	3,396 (13.2)	892 (12.9)	1,153 (12.8)	1,351 (13.8)	
Presentation					
Asymptomatic	14,718 (57.5)	3,844 (55.9)	5,117 (57.2)	5,757 (58.9)	.003
Symptomatic	9,263 (36.2)	2,586 (37.9)	3,268 (36.5)	3,409 (34.9)	
Rupture	1,619 (6.3)	451 (6.6)	568 (6.3)	600 (6.1)	
Transferred	6,528 (25.4)	1,915 (27.7)	2,236 (24.7)	2,377 (24.3)	<.0001
Insurer					
Medicare	11,245 (43.7)	3,433 (49.7)	4,110 (45.5)	3,702 (37.8)	<.0001
Private	7,795 (30.3)	2,439 (35.3)	2,946 (32.6)	2,410 (24.6)	
Other	6,680 (26.0)	1,029 (14.9)	1,979 (21.9)	3,672 (37.5)	
BMI	28.1 (6.4)	28.2 (6.4)	28.1 (6.3)	28.0 (6.4)	.274
Living at home	25,380 (98.7)	6,810 (98.6)	8,904 (98.6)	9,666 (98.8)	.331
Functional status					
Full/normal	16,242 (64.3)	4,733 (69.1)	5,680 (64.3)	5,829 (60.8)	<.0001
Light work	5,178 (20.5)	1,164 (17.0)	1,741 (19.7)	2,273 (23.7)	
Self-care	3,142 (12.4)	764 (11.2)	1,176 (13.3)	1,202 (12.5)	
Assistive care or bedbound	692 (2.7)	186 (2.7)	230 (2.6)	276 (2.9)	
Stroke	2,922 (11.4)	707 (10.2)	1,003 (11.1)	1,212 (12.4)	<.0001
Coronary disease	5,120 (19.9)	1,445 (20.9)	1,824 (20.2)	1,851 (19.0)	.004
CHF	3,523 (13.7)	812 (11.8)	1,226 (13.6)	1,485 (15.2)	<.0001
COPD	7,553 (29.4)	2,008 (29.1)	2,609 (28.9)	2,936 (30.0)	.203
DM	4,161 (16.2)	1,082 (15.7)	1,470 (16.3)	1,609 (16.5)	.383
Creatinine >1.7 or on dialysis	3,180 (12.4)	806 (11.7)	1,131 (12.6)	1,243 (12.8)	.104
HTN	21,712 (85.1)	5,752 (84.0)	7,581 (85.1)	8,379 (85.8)	.006
Smoking					
Never	6,679 (26.1)	1,783 (25.9)	2,317 (25.7)	2,579 (26.5)	.035
Prior	10,903 (42.6)	2,919 (42.5)	3,942 (43.8)	4,042 (41.5)	
Current	8,021 (31.3)	2,173 (31.6)	2,740 (30.4)	3,108 (31.9)	
Previous CABG	2,719 (10.6)	818 (11.9)	930 (10.3)	971 (9.9)	.0002
Previous PCI	3,733 (14.5)	960 (13.9)	1,331 (14.8)	1,442 (14.8)	.240
Previous CEA/CAS	765 (3.0)	223 (3.2)	282 (3.1)	260 (2.7)	.059
Previous aneurysm repair	5,861 (22.8)	1,355 (19.6)	2,098 (23.3)	2,408 (24.6)	<.0001
Previous bypass	1,411 (5.5)	366 (5.3)	505 (5.6)	540 (5.5)	.711
Previous PVI	1,264 (4.9)	320 (4.6)	410 (4.5)	534 (5.5)	.007
Previous aortic surgery	6,444 (25.1)	1,482 (21.5)	2,321 (25.7)	2,641 (27.0)	<.0001
Previous major amputation	127 (0.5)	39 (0.6)	49 (0.5)	39 (0.4)	.229
Genetic Hx	802 (3.4)	220 (3.5)	291 (3.5)	291 (3.3)	.613
Abnormal stress test	1,339 (5.2)	354 (5.1)	471 (5.2)	514 (5.3)	.925
Hemoglobin, g/dL					
>12	14,257 (55.7)	3,840 (55.9)	5,056 (56.2)	5,361 (55.1)	.045
10–12	7,084 (27.7)	1,957 (28.5)	2,442 (27.1)	2,685 (27.6)	
<10	4,251 (16.6)	1,075 (15.6)	1,500 (16.7)	1,676 (17.2)	
Preop ASA	13,916 (54.2)	3,656 (53.1)	5,001 (55.4)	5,259 (53.8)	.008
Preop statin	15,174 (59.1)	3,790 (55.0)	5,363 (59.5)	6,021 (61.7)	<.0001
Preop P2Y	2,621 (10.2)	671 (9.7)	910 (10.1)	1,040 (10.6)	.151
Preop beta-blocker	17,004 (66.2)	4,438 (64.5)	5,971 (66.2)	6,595 (67.5)	.0002
Preop ACE/ARB	10,517 (41.0)	2,786 (40.5)	3,659 (40.6)	4,072 (41.7)	.178
Preop anticoagulant	3,550 (13.8)	752 (10.9)	1,249 (13.9)	1,549 (15.9)	<.0001
Preop EF <50%	2,844 (11.1)	779 (11.3)	1,021 (11.3)	1,044 (10.7)	.310
Indication					
Aneurysm	14,323 (55.6)	3,937 (57.0)	4,974 (55.0)	5412 (55.3)	.036
Dissection	5,347 (20.8)	1,412 (20.4)	1,903 (21.1)	2,032 (20.8)	
Aortic syndrome	3,862 (15.0)	967 (14.0)	1,417 (15.7)	1,478 (15.1)	
Trauma or aortic thrombus	2,210 (8.6)	596 (8.6)	745 (8.2)	869 (8.9)	
Preop max aortic diameter	54.8 (17.0)	54.0 (17.0)	54.8 (16.6)	55.3 (17.4)	.0002
Extent of disease (distal zone-proximal zone)	2.9 (2.5)	2.7 (2.4)	2.9 (2.5)	3.1 (2.6)	<.0001

ACE, angiotensin-converting enzyme; *ARB*, angiotensin receptor blocker; *ASA*, American Society for Anesthesiologists; *BMI*, body mass index; *CEA*/*CAS*, carotid endarterectomy/carotid angioplasty; *CHF*, congestive heart failure; *COPD*, chronic obstructive pulmonary disease; *DM*, diabetes mellitus; *EF*, ejection fraction; *HTN*, hypertension; *Hx*, history; *PCI*, percutaneous coronary intervention; *preop*, preoperative; *PVI*, peripheral vascular intervention.

Table II
Procedural details of the study cohort, stratified by year of index intervention

Variable, *n* (%)	Overall ($N = 25,742$)	2015–2017 ($n = 6,912$; 27%)	2018–2020 ($n = 9,039$; 35%)	2021–2023 ($n = 9,791$; 38%)	*P* value
ASA class 4/5	14,548 (56.7)	3,883 (56.3)	5,071 (56.3)	5,594 (57.3)	.347
Contrast vol, mL	110 (71.3)	115 (73.7)	109 (71.0)	109 (69.8)	<.0001
Crystalloid vol, mL	1,881 (1219)	2,020 (1309)	1,843 (1198)	1,816 (1161)	<.0001
EBL, mL	145 [50,300]	150 [70,400]	100 [50,300]	100 [50,300]	<.0001
Fluoroscopy time, min	23 [10,53] (0, 300)	21 [10,53] (0, 300)	22 [10, 51] (0,292)	25 [11, 55] (0,300)	<.0001
Any intraoperative PRBCs	5,506 (21.5)	1,654 (24.1)	1,905 (21.3)	1,947 (20.0)	<.0001
Procedure time, min	176 (117)	182 (120)	172 (115)	177 (117)	<.0001
IVUS or TEE	11,296 (44.3)	3,013 (44.0)	3,932 (44.0)	4,351 (44.8)	.471
Arm/neck access	6,360 (24.9)	1,759 (25.6)	2,306 (25.8)	2,295 (23.5)	.0005
Number of aortic devices	1.9 (0.97)	1.9 (0.97)	1.9 (0.95)	1.9 (1.0)	.016
Iliac device	7,714 (30.6)	1,668 (26.0)	2,776 (30.9)	3,270 (33.4)	<.0001
Custom modified device	6,651 (26.0)	1,447 (21.1)	2,293 (25.6)	2,911 (29.8)	<.0001
Technical success	23,562 (95.2)	5,896 (95.6)	8,508 (95.5)	9,158 (94.7)	.017
Conversion to open	174 (0.7)	42 (0.6)	66 (0.7)	66 (0.7)	.637
False lumen	639 (2.5)	144 (2.1)	233 (2.6)	262 (2.7)	.047
Device access arterial injury	1,162 (4.5)	340 (4.9)	394 (4.4)	428 (4.4)	.158

ASA, American Society for Anesthesiologists; *EBL*, estimated blood loss; *IVUS*, intravascular ultrasound; *postop*, postoperative; *PRBC*, packed red blood cell; *TEE*, transesophageal echocardiography.

Discussion

Over the past 30 years, the rapid adoption and proliferation of TEVAR has led to it becoming the de facto treatment of choice for anatomically suited patients with thoracic aortic disease. In this current analysis, a comprehensive assessment of temporal trends in TEVAR use and outcomes are presented using a large contemporary national quality registry dataset from 2015 to 2023. This study of more than 25,000 procedures provides perspective on the evolving landscape of TEVAR practice and its association with changes in clinical outcomes across a spectrum of aortic pathologies. Our findings underscore TEVAR's established role as the primary therapeutic approach for both elective and nonelective descending thoracic aortic disease, aligning with current clinical practice guidelines in both Europe[3] and North America.[4] Using robust analytical methodology, we identified notable shifts in patient selection, procedural adjunct use and perioperative outcomes over time.

Although the overall center-level volume of TEVAR procedures remained stable, distinct patterns were evident surrounding preoperative indications and associated outcomes. Not surprisingly, elective procedures were most commonly performed for degenerative aneurysm indications while nonelective presentations included a greater proportion of dissection and PAU/IMH diagnoses. Interestingly, a trend toward increasingly complex patient risk profiles was detected, as determined by greater proportions of individuals with compromised preoperative functional status and history of prior aortic surgery undergoing repair, as well as a

Table III
Postoperative complications of the study cohort, stratified by year of index intervention

Outcome, *n* (%)	Overall ($N = 25,742$)	2015–2017 ($n = 6,912$; 27%)	2018–2020 ($n = 9,039$; 35%)	2021–2023 ($n = 9,791$; 38%)	*P* value
30-d mortality	1,609 (7.7)	461 (7.1)	572 (6.7)	576 (9.9)	<.0001
In-hospital death	1,416 (5.5)	401 (5.8)	488 (5.4)	527 (5.4)	.451
Any postoperative complication	5,862 (22.8)	1,732 (25.1)	2,063 (22.9)	2,067 (21.2)	<.0001
ICU days	2 [1,4] (0,135)	3 [1,5] (0,100)	2 [1,4] (0,100)	2 [1,4] (0,135)	<.0001
Postop LOS	4 [2,8]	5 [3,8]	4 [2,8]	4 [2,8]	<.0001
Any postop PRBC	8,465 (33.2)	2,346 (34.1)	3,000 (33.6)	3,119 (32.0)	.009
Postop spinal drain	7,399 (28.8)	2,585 (37.5)	2,795 (31.0)	2,019 (20.7)	<.0001
Postop vasopressors	6,821 (26.6)	1,752 (25.5)	2,415 (26.8)	2,654 (27.2)	.038
Complications					
Myocardial infarction	635 (2.5)	185 (2.7)	191 (2.1)	259 (2.7)	.027
Dysrhythmia	1853 (7.2)	585 (8.5)	625 (6.9)	643 (6.6)	<.0001
CHF	413 (1.6)	126 (1.8)	127 (1.4)	160 (1.6)	.110
Cerebrovascular symptoms	826 (3.2)	236 (3.4)	282 (3.1)	308 (3.2)	.522
Respiratory complications	2041 (7.9)	624 (9.0)	692 (7.7)	725 (7.4)	.0003
Dialysis	759 (3.0)	215 (3.2)	249 (2.8)	295 (3.1)	.412
Arm embolism	168 (0.7)	45 (0.7)	63 (0.7)	60 (0.6)	.774
Leg embolism	434 (1.7)	134 (1.9)	150 (1.7)	150 (1.5)	.130
Leg compartment syndrome	205 (0.8)	56 (0.8)	77 (0.9)	72 (0.7)	.662
Intestinal ischemia	519 (2.0)	150 (2.2)	177 (2.0)	192 (2.0)	.571
Renal ischemia	617 (2.4)	174 (2.5)	222 (2.5)	221 (2.3)	.503
Compromised leg motor function	487 (1.9)	137 (2.0)	188 (2.1)	162 (1.7)	.082
Postop spinal cord ischemia					
None	24,792 (96.6)	6,662 (96.6)	8,673 (96.2)	9,457 (96.9)	.102
Transient	390 (1.5)	96 (1.4)	150 (1.7)	144 (1.5)	
At discharge	492 (1.9)	137 (2.0)	192 (2.1)	163 (1.7)	
Reoperation related to TEVAR	1,655 (6.5)	428 (6.3)	600 (6.7)	627 (6.5)	.517

CHF, congestive heart failure; *postop*, postoperative; *ICU*, intensive care unit; *postop*, postoperative; *PRBC*, packed red blood cell; *TEVAR*, thoracic endovascular aortic repair.

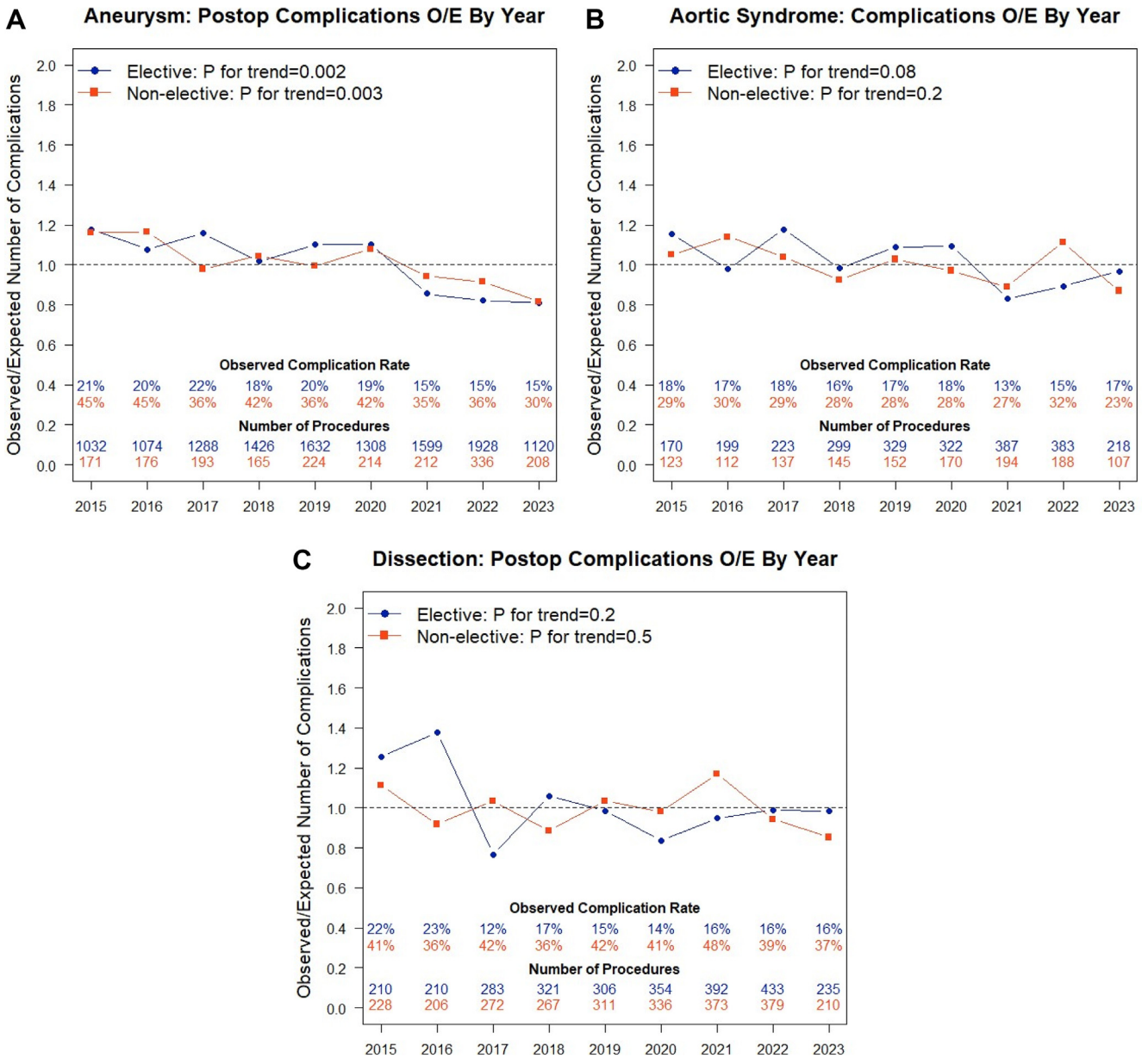

Figure 2. Trend for observed compared with expected in-hospital complications rates after endovascular aortic repair, stratified by indication: (A) aneurysms; (B) aortic syndromes; (C) dissections. *O*/*E*, observed/expected.

proportional increase in the use of custom-made stent-grafts, since adoption rates for total endovascular repair of thoracic aortic pathologies involving the supra-aortic trunks have already been shown to increase over recent years.[5,6] Despite an overall decline in the rate of in-hospital complications among elective and nonelective TEVARs, risk-adjusted 30-day mortality rates improved for elective cases but showed no change for nonelective procedures.

Findings from the current study should be interpreted within the context of the available literature in order to highlight similarities and differences that may inform clinical practice and drive future research. In a recent study from the International Consortium of Vascular Registries, Hellgren et al[7] analyzed the perioperative results of TEVAR in a cohort of 9,518 patients who had been treated across a range of pathologies, including aneurysms ($n = 4,436$), type B dissections ($n = 3,976$), and traumas ($n = 1,106$) from 2012 to 2016. According to this study, perioperative mortality after TEVAR for intact and ruptured aneurysms was 5% and 27% respectively (for comparison, corresponding rates for the present analysis ranged between 2% and 4% for elective aneurysms and 11% and 20% for nonelective aneurysms), with a composite complication rate (defined as stroke, paraplegia, dialysis, and mortality) approaching 13% and 40%, respectively. The rate of postoperative mortality after TEVAR for acute and chronic dissections was almost 10% and 3%, respectively (for comparison, corresponding rates for the present analysis ranged between 1% and 3% for elective dissections and 10% and 16% for nonelective dissections), with the corresponding incidence of complications reported to be as high as 20% and 7%, respectively. Although the study by Hellgren et al[7] certainly contributes to current knowledge owing to inclusion of data from multiple countries and highlighting how timing of intervention influences peri-operative outcomes, it lacked a detailed analysis of trends over time. In this sense, our study

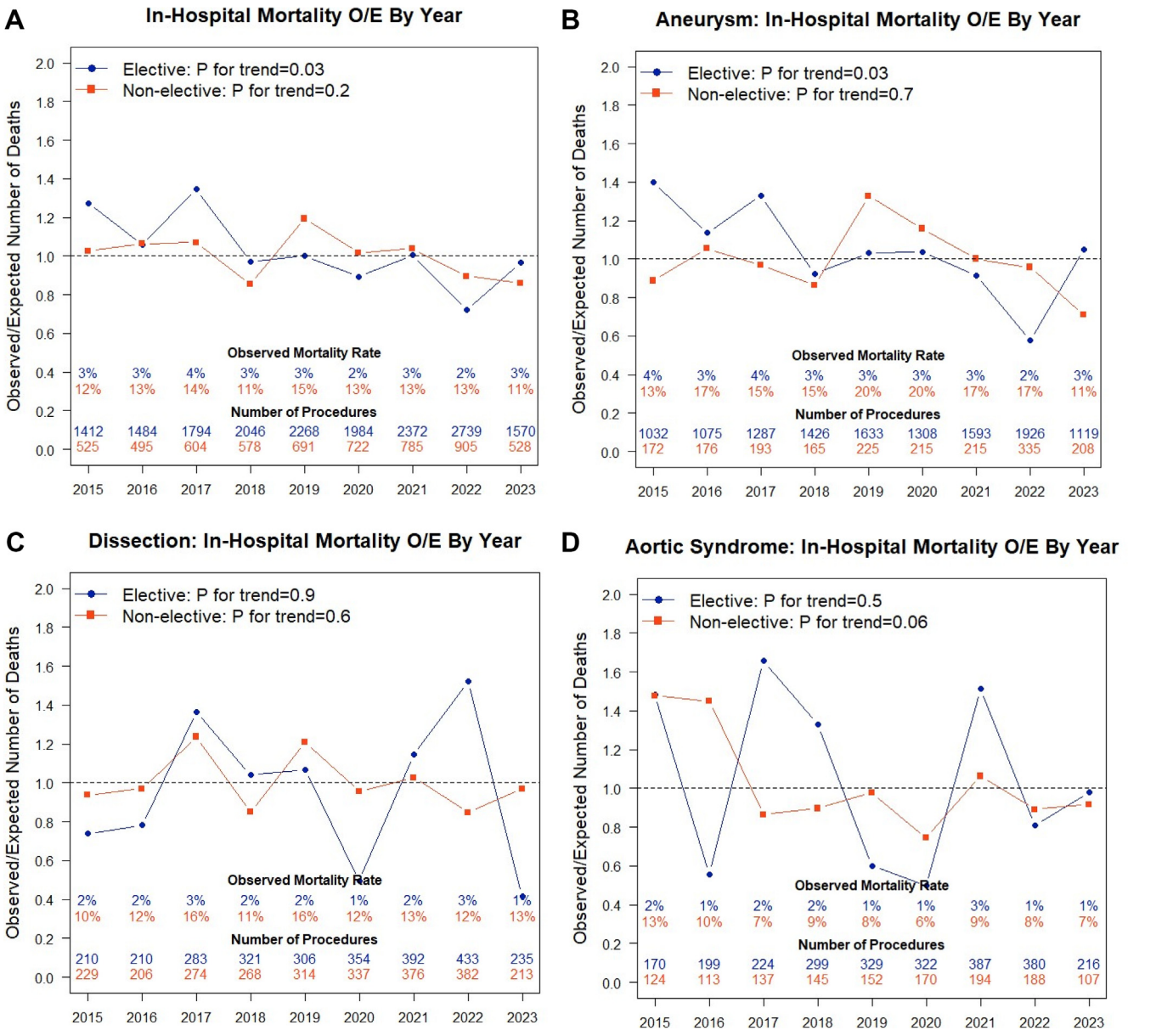

Figure 3. Trend for observed vs expected in-hospital mortality rates after endovascular aortic repair, stratified by indication: (A) overall; (B) aneurysms; (C) dissections; (D) aortic syndromes. *O*/*E*, observed/expected.

leverages a significantly larger dataset, enabling robust statistical analyses, and facilitates more nuanced interpretations about practice variation and evolution of outcomes longitudinally.

Overall, we observed a perioperative mortality rate of approximately 5.3% that appeared to incrementally decrease across the study period, although it marginally increased in nonelective presentations, which could reflect a shifting practice pattern toward offering TEVAR more liberally for increasingly challenging clinical scenarios. This potential explanation is not only supported by increasing prevalence of surrogate markers for operative complexity such as previous aortic surgery history and greater total procedure time, but also a broader implementation of custom-made endograft technology. Nonetheless, we were able to identify relevant time-related trends toward a generalized reduction of perioperative mortality and complications after elective presentations especially among the aneurysm-related procedures. In contrast, TEVAR for dissection indications appeared to be associated consistently with greater rates of perioperative morbidity and mortality, which did not significantly decrease over time. Clearly, this may in part reflect underlying differences in baseline patient and anatomic risk profiles owing to fundamental disparities among these pathologies, as well as to different practice for care of patients presenting with diverging thoracic aorta pathologies. It is not surprising that our findings for trends in nonelective outcomes were inferior to elective procedures. However, we believe that further improvement in technology, imaging, analysis of big data, as well as potential centralization of care may lead to demonstrative gains in clinical care delivery for these challenging cases.

It was not surprising that dissection and PAU/IMH presentations represented a larger proportion of nonelective cases with less improvement in outcomes across the study interval. These findings might also provide a more realistic picture of contemporary real-

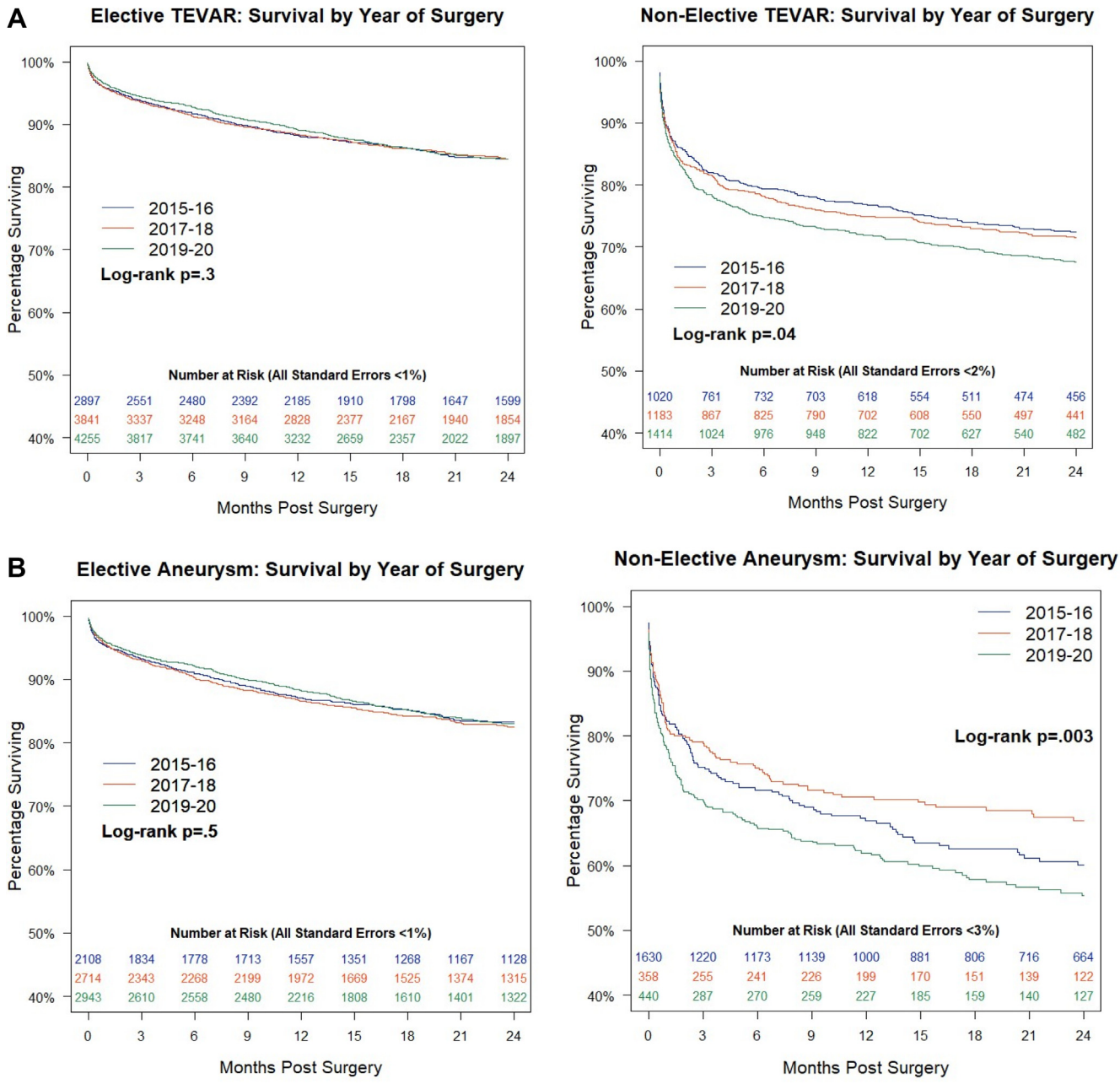

Figure 4. Long-term survival after endovascular aortic repair, stratified by indication and timing of repair: (A) overall (*left*: elective; *right*: nonelective); (B) aneurysms (*left*: elective; *right*: nonelective); (C) dissections (*left*: elective; *right*: nonelective); and (D) aortic syndromes (*left*: elective; *right*: nonelective).

world outcomes in unselected populations with overall rare diseases, which are traditionally difficult to study. For instance, in a recent study from the Global Registry of Endovascular Aortic Treatment (>5,000 patients were enrolled in the GREAT from 113 centers in 14 countries across 4 continents treated between 2019 and 2016), Tjaden et al[8] were able to find a total of 264 patients who underwent TEVAR for dissections (64% acute, $n = 170$). Early postoperative complications occurred in 9% of patients, with no difference in chronic vs acute dissection. Additionally, these authors reported 30-day aortic-related mortality and all-cause mortality to be 1.5% and 2.3% respectively, with no differences on the basis of chronicity. Therefore, our analysis can further help establish outcome benchmarks to further identify areas for TEVAR quality improvement, as it provides a national depiction of practice trends and outcomes that will inform regulatory and industry stakeholders, as well as aid with patient-provider shared decision-making.

Concordant with recent trends, we identified a consistent reduction in the use of preoperative cerebrospinal fluid drains (CSFDs), which was not associated with a reciprocal increase in the observed postoperative SCI rates. In fact, much debate has recently been held on whether the use of lumbar drains remains justified in the contemporary era, with most experts advocating for strict implementation policies only in patients deemed at 'high-risk' for neurological injury after TEVAR.[9] Accordingly, recent meta-analyses and large experiences have reported a low rate of SCI

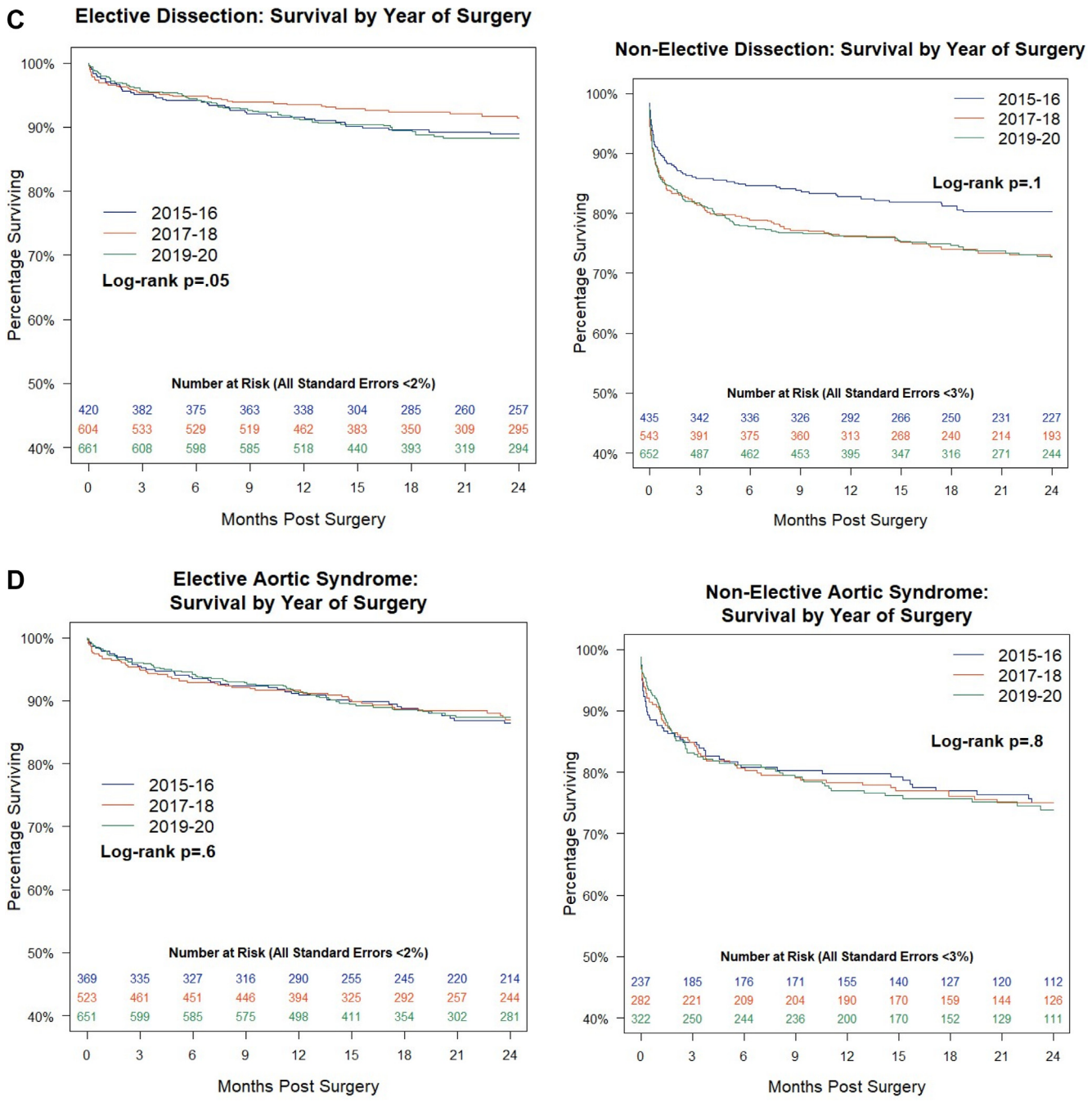

Figure 4. (*continued*).

occurring without prophylactic CSFD and non-negligible rates of CSFD-related morbidity.[10] Specifically, there is a notable incidence of death, drain-related complications, and catheter dysfunction that may not justify routine use of pre-emptive drain placement for all patients who undergo TEVAR. These observed trends in practice variation surrounding drain use and SCI rates highlight translation of the evolution in the peer-reviewed evidence into real-world practice and further underscores the relevance of the current analysis to catalogue these changes. Further changes were noted in practice patterns such as for instance increased use of IVUS, a relatively well-described tool that can facilitate TEVAR planning and execution, in which concurs with results of previous research.[11,12] Taken altogether, these findings highlight notable shifts in the use of procedural adjuncts that, coupled together with improved knowledge of aortic pathologies and better perioperative care bundles, may have contributed to the improved postoperative results.

Importantly, the findings from the sensitivity analysis (which confirmed that outcomes were consistent across centers with different procedural volumes), closely mirror those from recent research in the field of abdominal aortic disease that point towards a close volume-outcome relationship for open surgery but not for endovascular repair in both elective and nonelective clinical scenarios.[13-15] Lastly, it is worth highlighting that despite improvements in overall perioperative TEVAR outcomes, such changes did not seem to correlate with long-term survival benefit. One plausible explanation for this finding may be a more liberal adoption of endovascular repair among increasingly co-morbid

patients who were previously deemed inoperable or who had finite anticipated survival. In the current era, where cost-effectiveness plays an increasingly important role in the health care delivery paradigm, these finding should be taken into consideration and ultimately reflected in practice guidelines designed for optimizing care provision internationally.

Study limitations

The findings from the current analysis should be interpreted within the context of its limitations. First, the study may raise questions about the generalizability of large North American registry data to different health care systems internationally, although it should be noted that previous analyses have documented comparable mortality estimates derived from various European and US datasets. Nevertheless, it must be acknowledged that there are fundamentally different and unique features across countries, centers, and different patient groups that may have an unmeasurable impact on population level outcomes. We must also highlight that there are potential limitations in using VQI registry data as a proxy to definitively depict trends in care in the United States. Specifically, we are unable to capture care delivery at nonparticipating centers. This limitation may inadvertently lead to confounding in our observations. Moreover, the current analysis cannot account for the center and/or physician-level selection bias that undoubtedly affected observed outcomes. However, the use of a national quality registry that undergoes routine audits to ensure sequential capture of all eligible patients undergoing TEVAR at participating centers helps to mitigate some of this vulnerability to the analysis. Furthermore, some patient-level data (such as the exact type of custom-made stent-grafts that were used) could not be retrieved from the dataset. Notably, the current analysis does not provide descriptions of patients who did not receive operations so we can neither comment on natural history of disease under surveillance nor describe the denominator of patients at any single center that may have been turned down for an operation. The SVS-VQI TEVAR registry does not record center outcomes for open thoracic and/or thoracoabdominal aortic disease so we are unable to assess the center-level relationship between variable use of endovascular and open repair strategies in the management of thoracic aortic disease. Similarly, we focused on TEVAR procedures and did not analyze more complex endovascular cases such as fenestrated/branched repairs, so the impact of centers adopting these strategies is unmeasured in the current analysis. Finally, it is important to acknowledge the inherent limitations of the VQI registry to depict clinical nuances among different indications for TEVAR. This shortcoming may account for unanticipated and/or unmeasured confounding in our documented results. Nevertheless, given the prognostic signature associated with different thoracic aortic pathologies, we felt that the classification and delineation of the indications, as well as the timing of intervention was justified given the nature of real-world results in a registry.

In conclusion, in this comprehensive contemporary analysis of real-world data, there was minimal evidence to suggest that there has been a sustained increase in TEVAR procedures at the center level, underscoring what appears to be a plateau in use. However, there were multiple noteworthy improvements in TEVAR care delivery that included a decrease in in-hospital mortality for elective cases, a substantial reduction in preoperative spinal drain use accompanied by a corresponding decrease in postoperative SCI after elective procedures, and an overall decline in in-hospital complication rates. Among elective cases, there was a change in long-term mortality, with aneurysm patients exhibiting notably shorter survival compared with those with dissection or PAU/IMH. Conversely, nonelective operations had an observed increase in out of hospital mortality risk. This analysis offers contemporary insights into TEVAR practice patterns and clinical outcomes, providing valuable information for stakeholders focused on enhancing care delivery for this complex patient population.

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CRediT authorship contribution statement

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at [https://doi.org/10.1016/j.surg.2025.109153].

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