Extent of aortic replacement and operative outcome in open proximal thoracic aortic aneurysm repair

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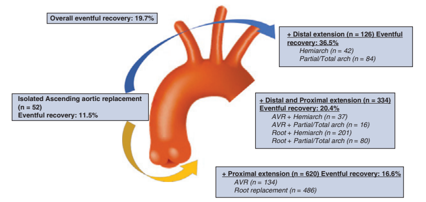
ABSTRACT

Objectives: There are few data to delineate the risk differences among open aortic procedures. We aimed to investigate the influence of the procedural types on the outcomes of proximal thoracic aortic aneurysm repair.

Methods: Among 1900 patients who underwent aortic replacement in our institution between 2005 and 2019, 1132 patients with aortic aneurysm who underwent a graft replacement of proximal thoracic aorta were retrospectively reviewed. Patients were divided into 4 groups based on the extent of the aortic replacement: isolated ascending aortic replacement (n = 52); ascending aortic replacement with distal extension with hemiarch, partial arch, or total arch replacement (n = 126); ascending aortic replacement with proximal extension with aortic valve or root replacement (n = 620); and ascending aortic replacement with distal and proximal extension (n = 334). "Eventful recovery," defined as occurrence of any key complications, was used as the primary end point. Odds ratios for inability to achieve uneventful recovery in each procedure were calculated using ascending aortic replacement as a reference.

Results: Overall, in-hospital mortality and stroke occurred in 16 patients (1.4%) and 24 patients (2.1%). Eventful recovery was observed in 19.7% of patients: 11.5% in those with ascending aortic replacement, 36.5% in those with partial arch or total arch replacement, 16.6% in those with proximal extension with aortic valve or root replacement, and 20.4% in those with distal and proximal extension ($P < .001$). With ascending aortic replacement as the reference, a multivariable logistic regression revealed partial arch or total arch replacement (odds ratio, 10.0; 95% confidence interval, 1.8-189.5) was an independent risk factor of inability to achieve uneventful recovery.

Conclusions: Open proximal aneurysm repair in the contemporary era resulted in satisfactory in-hospital outcomes. Distal extension was associated with a higher risk for postoperative complications. (JTCVS Open 2022;12:1-12)



Eventful recovery rates by replacement extent after open proximal aortic aneurysm repair.

CENTRAL MESSAGE

Although contemporary open proximal aortic aneurysm repair results in excellent postoperative outcomes, caution must be exercised when extending the aortic replacement to the distal aortic arch.

PERSPECTIVE

This study showed the association between the extension of the aortic replacement and the rate of complications. The data suggest a key role of procedural type in developing risk assessment models as well as recommendations for surgical repair of aneurysm.

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Thoracic aortic surgery is becoming increasingly important in adult cardiac surgery. A recent Nationwide Inpatient Sample Study showed increasing surgical procedural volumes for both proximal thoracic aortic aneurysm and acute aortic syndrome.[1] In the Society of Thoracic Surgeons adult cardiac surgery database, open aortic procedures accounted for 7.3% of the cases recorded between July 2017 and June 2018.[2] Thoracic aortic surgery is acknowledged as a subspecialty that requires expertise and experience,[3,4] and the association between surgical volume and outcomes has been reported.[5,6] However, thoracic aortic surgery

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Abbreviations and Acronyms

ASC = ascending aortic replacement
AVR = aortic valve replacement
CI = confidence interval
D+P = ascending aortic replacement with distal and proximal extension
DST = ascending aortic replacement with distal extension with hemiarch, partial arch, or total arch replacement
OR = odds ratio
PRX = ascending aortic replacement with proximal extension with aortic valve replacement or aortic root replacement

continues to be practiced by low-volume surgeons and programs because of the nature of aortic emergencies.[7] The temporal trend of increasing case volume might enhance this practice pattern, and at this time, defining the standards in outcome measurement and quality assurance is becoming necessary in this subspecialty. A unique and wide variability in thoracic aortic surgery challenges application of a simple risk prediction model at present. Among such important variables, particularly relevant to surgeons, may be the procedure type. Previous studies have typically reported the results of certain procedures, such as aortic root replacement or total arch replacement, separately in thoracic aortic surgery[8-12]; however, there are few data to delineate the risk differences among these complex procedures. In addition to a role for risk assessment of individual patients, understanding such risk differences would have an important clinical implication for the guideline-recommended surgical indication, for which the same size criteria are currently applied for all aneurysms from the root to the arch, for each of which a different procedure would be required.

The aims of this study were (1) to describe the contemporary outcomes of various open thoracic aortic surgical procedures for proximal aortic aneurysm performed in a tertiary aortic center and (2) to investigate the influence of the procedural type on the outcomes of proximal thoracic aortic aneurysm repair.

MATERIALS AND METHODS

Study Design and Patient Selection

The Columbia University Medical Center Institutional Review Board approved this study and waived the requirement for informed consent (Abbreviated Title: Outcomes in Aortic Surgery; Number: AAAR2949; First approval date: 08/10/2017; Most recent approval date: 03/11/2021).

This is a single-center retrospective study of 1132 patients with aortic aneurysm who underwent a graft replacement of the proximal aorta between March 2005 and December 2019. Proximal thoracic aorta was defined as an aortic segment from the aortic root to the proximal descending thoracic aorta.[13,14] Patients who had aortic dissection or infective endocarditis and needed urgent/emergency surgery or concomitant surgery other than an aortic valve procedure were excluded. Patients were divided into 4 groups based on the extent of the aortic replacement: isolated ascending aortic replacement (ASC, n = 52); ascending aortic replacement with distal extension with hemiarch, partial arch, or total arch replacement (DST, n = 126); ascending aortic replacement with proximal extension with aortic valve replacement or aortic root replacement (PRX, n = 620); ascending aortic replacement with distal and proximal extension (D+P, n = 334); Figure 1. Preoperative demographics, procedural details, and postoperative complications (following the definition by the Society of Thoracic Surgeons Adult Cardiac Database Version 2.9 whenever available) were collected by reviewing the electronic medical record.

"Eventful recovery" was used as the primary end point. The eventful recovery was defined as occurrence of any one of the following postoperative complications, including 30-day mortality, stroke, reexploration for bleeding, respiratory failure, acute renal failure, deep sternal wound infection, postcardiotomy shock, and permanent pacemaker implantation. Our previous study in aortic root replacement showed that uneventful recovery was associated with better long-term survival.[15]

Patient Management and Surgical Procedure

The surgical indication was determined by each attending surgeon, following the Guidelines of the time.[13,14] In general, for aneurysms 55 mm or larger, an open repair was recommended. For aneurysms 50 to 55 mm, repair was selectively recommended based on the individual risk profiles. For aneurysms 45 to 50 mm, a concomitant repair was performed for patients who needed aortic valve surgery. The extent of the aortic resection was per the discretion of the attending surgeon. Typically, an aortic segment of 40 mm or larger adjacent to the main aneurysm was resected. For aortic root replacement, the aortic valve was spared with reimplantation technique whenever appropriate as previously described.[16-18] When aortic valve replacement (AVR) was required, the choice of the prosthetic valve was determined in accordance with the Guidelines[19,20] and patient's preference. The arterial cannulation site was at the distal ascending aorta unless the resection area included the aortic arch, in which case the axillary artery was an option per the surgeon's preference.[21] For the arch replacement, the distal aortic anastomosis was performed typically with moderate hypothermia (24-28 °C in nasopharyngeal temperature) and antegrade cerebral perfusion. Distal systemic perfusion was temporarily halted until completion of the distal aortic anastomosis. A brief period of retrograde cerebral perfusion was selectively added to clear any air or debris from the cerebral circulation. For hemiarch replacement, unilateral antegrade cerebral perfusion through the axillary artery or innominate artery was performed unless near-infrared spectroscopy showed decreased oxygen saturation on the left head, requiring conversion to bilateral cerebral perfusion by inserting a perfusion cannula into the left carotid artery. For more extensive arch replacement, bilateral cerebral perfusion was typically used as previously described.[22] After the distal anastomosis was completed, systematic perfusion was resumed from the side branch of the graft. The supra-aortic vessels were individually reconstructed using a multi-branch graft.

Statistical Analysis

Variables of baseline characteristics, operative details, and in-hospital outcomes were evaluated. Continuous variables were tested for normality using the Kolmogorov–Smirnov test and found to be not normally distributed. They were expressed as medians (interquartile ranges) and analyzed using the Kruskal–Wallis test. Categorical data described with numbers and percentages of the total were compared using the Pearson's chi-square test or Fisher exact test, as appropriate. An alpha level of .05 was used to establish statistical significance of the overall test. Bonferroni correction was applied to assess the difference in variables for 6 pairwise comparisons among 4 groups of patients, categorized based on the extent of the aortic replacement. To declare statistical significance among these 4 groups, 6 different multiple comparisons must be made, so the P value must be less than .0083 (0.05 divided by 6).

Univariable logistic regression was performed to investigate the impact of each variable on our primary end point, which is the uneventful recovery. Variables significant at P less than .1 and the extent of the aortic replacement were entered into the multivariable logistic regression analysis to determine the independent risk factors associated with failure to achieve uneventful recovery. Model fit was assessed using the Hosmer–Lemeshow goodness-of-fit statistics, for which a small P value less than .05 may suggest poor fit. We also validated our model using the c-statistics, for which a value of less than .5 may indicate violation to predictive accuracy. All statistical analyses were performed with R version 4.0.0 (R Foundation for Statistical Computing).

RESULTS

Patient Characteristics

The baseline characteristics of all patients are presented in Table 1. The median age was 60.0 [49.0-70.0] years, and 24.3% were women. The patients in the DST group were older with more comorbidities, including hypertension, cerebrovascular disease, and peripheral arterial disease, whereas coronary artery disease and chronic kidney disease were more common in PRX. Approximately half of the patients had significant aortic insufficiency, and one-quarter had AS with 38% having bicuspid aortic valve.

Median diameters of the aortic root, ascending aorta, and proximal aortic arch were 46.0 (39.0-52.0) mm, 50.0 (46.0-55.0) mm, and 34.0 (30.0-36.0) mm, respectively. The maximum aneurysm diameter was greatest in DST (56.0 [51.0-60.0] mm vs 51.0 [49.8-54.3] mm in ASC vs 50.0 [47.0-54.0] mm in PRX vs 55.0 [49.3-60.0] mm).

Operative Details

The operative details are listed in Table 2. Isolated ascending replacement was rarely performed (4.6%), with proximal extension being the most common procedure. Circulatory arrest was used for 2 patients in the ASC group and 1 patient in the PRX group. All had a history of previous cardiovascular surgery, and circulatory arrest was required to manage the severe adhesions (1 had a CentriMag [Abbott] implantation, the second had a previous ascending aortic replacement, and the third had an AVR for infective endocarditis). Among the patients in DST and D+P, hemiarch replacement was performed in 60.9% (280/460), partial arch replacement was performed in 8.0% (37/460), and total arch replacement was performed in 31.1% (143/460). In PRX, the proximal extension was AVR in 21.6% (134/620), valve-sparing aortic root replacement in 34.7% (215/620), and Bentall procedure in 43.7% (271/620). Patients with D+P underwent AVR + hemiarch replacement in 11.1% (37/334), AVR + partial/total arch replacement in 4.8% (16/334), aortic root + hemiarch replacement in

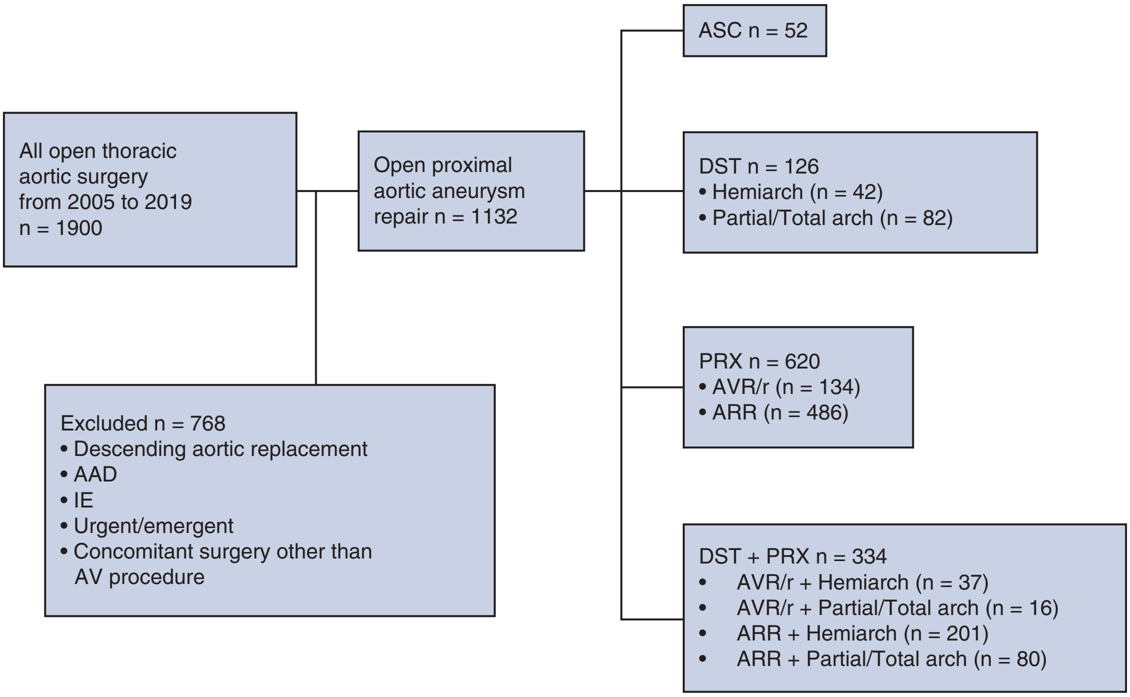

FIGURE 1. Consort type diagram of patients with ASC, ascending + hemiarch, DST, PRX, or DST + PRX. *ASC*, Open thoracic aortic aneurysm repair undergoing isolated ascending aortic replacement; *DST*, partial arch or total arch replacement; *PRX*, ascending + aortic valve replacement or aortic root replacement; *AVR*, aortic valve replacement; *ARR*, aortic root replacement; *IE*, infective endocarditis; *AV*, aortic valve.

TABLE 1. Baseline characteristics

Variable*	Overall (n = 1132)	ASC (n = 52)	DST (n = 126)	PRX (n = 620)	D+P (n = 334)	*P* value
Age, y	60.0 [49.0-70.0]	65.0 [51.8-71.3]	66.0 [56.3-74.0]	59.0 [48.0-67.0]	61.0 [51.0-69.8]	<.001‖,¶,#
Gender, female	275 (24.3)	20 (38.5)	61 (48.4)	126 (20.3)	68 (20.4)	<.001‡,§,‖,¶
BSA, m^2	2.0 [1.8-2.2]	1.9 [1.8-2.1]	1.9 [1.7-2.1]	2.0 [1.9-2.2]	2.0 [1.8-2.2]	<.001‖,¶,#
Hypertension	784 (69.3)	44 (84.6)	109 (86.5)	414 (66.8)	217 (65.0)	<.001§,‖,¶
Dyslipidemia	548 (48.4)	22 (42.3)	73 (57.9)	305 (49.2)	148 (44.3)	.051**
Diabetes	113 (10.0)	6 (11.5)	17 (13.5)	58 (9.4)	32 (9.6)	.532**
Marfan syndrome	26 (2.3)	1 (1.9)	3 (2.4)	18 (2.9)	4 (1.2)	.415**
CAD	133 (11.7)	1 (1.9)	3 (2.4)	77 (12.4)	52 (15.6)	<.001‖,¶
PMI	27 (2.4)	0	1 (0.8)	17 (2.7)	9 (2.7)	.374**
CVD	82 (7.2)	1 (1.9)	22 (17.5)	35 (5.6)	24 (7.2)	<.001*,‖,¶
COPD	98 (8.7)	6 (11.5)	16 (12.7)	42 (6.8)	34 (10.2)	.075**
PAD	112 (9.9)	15 (28.8)	41 (32.5)	38 (6.1)	18 (5.4)	<.001‡,§,‖,¶
CKD	414 (36.6)	6 (11.5)	31 (24.6)	234 (37.7)	143 (42.8)	<.001‡,§,‖,¶
Afib	80 (7.2)	1 (2.0)	9 (7.6)	45 (7.3)	25 (7.6)	.544**
Previous cardiac surgery	80 (7.2)	2 (3.8)	17 (13.6)	36 (5.8)	25 (7.5)	.015‖
LVEF, %	55.0 [51.0-60.0]	55.0 [54.3-60.0]	55.0 [55.0-60.0]	55.0 [51.0-60.0]	55.0 [50.0-58.0]	.006¶
AI moderate or more	579 (52.4)	13 (25.5)	26 (21.7)	340 (55.7)	200 (61.5)	<.001‡,§,‖,¶
AS moderate or more	288 (26.2)	1 (2.0)	1 (0.8)	186 (30.7)	100 (30.8)	<.001‡,§,‖,¶
Bicuspid aortic valve	428 (37.8)	8 (15.4)	6 (4.8)	274 (44.2)	140 (41.9)	<.001‡,§,‖,¶
Size of aortic root, mm	46.0 [39.0-52.0]	38.0 [34.0-43.0]	37.0 [34.0-41.3]	47.0 [40.0-52.0]	48.0 [41.0-55.0]	<.001‡,§,‖,¶
Size of ascending aorta, mm	50.0 [46.0-55.0]	51.0 [50.0-54.5]	53.5 [48.3-60.0]	48.0 [44.0-52.3]	53.0 [48.0-60.0]	<.001‡,‖,#
Size of proximal arch, mm	34.0 [30.0-36.0]	32.0 [30.0-35.0]	40.0 [35.0-50.0]	31.5 [29.0-35.0]	35.0 [32.0-38.0]	<.001†,§,‖,¶,#
Maximum size or aorta, mm	52.0 [48.0-56.0]	51.0 [49.8-54.3]	56.0 [51.0-60.0]	50.0 [47.0-54.0]	55.0 [49.3-60.0]	<.001†,§,‖,#

ASC, Ascending aortic replacement; *DST*, ascending aortic replacement with distal extension with hemiarch, partial arch, or total arch replacement; *PRX*, ascending aortic replacement with proximal extension with aortic valve replacement or aortic root replacement; *D+P*, ascending aortic replacement with distal and proximal extension; *BSA*, body surface area; *CAD*, coronary artery disease; *PMI*, prior myocardial infarction; *CVD*, cerebrovascular disease; *COPD*, chronic obstructive pulmonary disease; *PAD*, peripheral artery disease; *CKD*, chronic kidney disease; *Afib*, atrial fibrillation; *LVEF*, left ventricular ejection fraction; *AI*, aortic insufficiency; *AS*, aortic stenosis. *Data are presented as median [IQR], or as number (%). †Significantly different between ASC and DST. ‡Significantly different between ASC and PRX. §Significantly different between ASC and D+P. ‖Significantly different between DST and PRX. ¶Significantly different between DST and D+P. #Significantly different between PRX and D+P. **No difference in all the comparisons of the 4 groups.

60.2% (201/334), and aortic root + partial/total arch replacement in 24.0% (80/334). The cardiopulmonary bypass time and aortic crossclamp time were longer in the descending order of D+P, DST, PRX, ASC and D+P, PRX, DST, ASC (both $P < .001$).

In-Hospital Mortality, Stroke, and 30-Day Mortality

The postoperative outcomes are shown in Table 3. The overall in-hospital mortality and 30-day mortality were low as 1.4% (n = 16) and 1.5% (n = 17) among 1132 patients, respectively: Three died of cardiogenic shock, 4 died of postoperative stroke, 4 died of multisystem organ failure, 2 died of septic shock, 2 died of hypovolemic shock, and 3 died of respiratory failure. The total incidence of stroke was 2.1% (n = 24).

The in-hospital mortality and stroke rates were 1.9% and 1.9% in ASC, 4.0% and 9.5% in DST, 0.3% and 1.1% in PRX, 2.4% and 1.2% in D+P, respectively. Of 12 patients with postoperative stroke in DST, 3 underwent hemiarch, 2 underwent partial arch replacement, and 7 underwent total arch replacement.

Eventful Recovery

Eventful recovery occurred in 19.7% of overall patients who underwent open proximal aortic aneurysm repair. As the extent of aortic replacement was expanded, the probability of eventful recovery increased: 11.5% in ASC, 16.6% in PRX, 20.4% in D+P, and 36.5% in DST. This observation was most prominent in respiratory failure: 23.8% in DST, 8.4% in D+P, 4.2% in PRX, and 5.8% in ASC; Figure 2.

Analysis for the Impact of the Extent of Aortic Replacement on Uneventful Recovery

In a multivariable logistic regression analysis for eventful recovery (Table 4), DST was found to be an independent

TABLE 2. Operative details

Variable*	Overall (n = 1132)	ASC (n = 52)	DST (n = 126)	PRX (n = 620)	D+P (n = 334)	P value
VSRR	312 (27.6)	-	-	215 (34.7)	97 (29.0)	<.001‡,§,||,¶
Bioprosthetic valve-conduit	406 (35.9)	-	-	236 (38.1)	170 (50.9)	<.001‡,§,||,¶,#
Mechanical valve-conduit	49 (4.3)	-	-	35 (5.6)	14 (4.2)	.014**
Aortic valve replacement	187 (16.5)	-	-	134 (21.6)	53 (15.9)	<.001‡,||,¶
Hemiarch replacement	280 (24.7)	-	42 (33.3)	-	238 (71.3)	<.001†,§,||,¶,#
Zone 1 or 2 arch replacement	37 (3.3)	-	11 (8.7)	-	26 (7.8)	<.001||,#
Total arch replacement	143 (12.6)	-	73 (57.9)	-	70 (21.0)	<.001†,§,||,¶,#
CPB time, min	125.0 [99.0-159.0]	68.0 [52.5-92.0]	132.0 [95.0-179.5]	120.0 [98.0-149.0]	140.0 [113.5-174.0]	<.001†,§,||,#
ACC time, min	91.0 [70.0-119.0]	39.5 [31.3-50.3]	60.0 [46.0-78.0]	94.0 [76.0-120.8]	103.0 [78.0-133.0]	<.001††
Circulatory arrest	463 (40.9)	2 (3.8)	126 (100)	1 (0.2)	334 (100)	<.001†,‡,§,||,#
Circulatory arrest time, min	-	21.0	19.0 [9.0-41.0]	14.0	12.0 [10.0-16.0]	-
Minimum body temperature, °C	-	19.5	28.0 [24.0-28.0]	20.0	28.0 [28.0-28.0]	-
ACP	288 (25.4)	-	78 (61.9)	-	210 (62.9)	<.001†,§,||,#
RCP	22 (1.9)	1 (1.9)	8 (6.3)	-	13 (3.9)	<.001†,||,#
ACP+RCP	151 (13.3)	-	40 (31.7)	-	111 (33.2)	<.001†,§,||,#
DHCA	2 (0.2)	1 (1.9)	-	1 (0.2)	-	1**

ASC, Ascending aortic replacement; *DST*, ascending aortic replacement with distal extension with hemiarch, partial arch, or total arch replacement; *PRX*, ascending aortic replacement with proximal extension with aortic valve replacement or aortic root replacement; *D+P*, ascending aortic replacement with distal and proximal extension; *VSRR*, valve-sparing aortic root replacement; *CPB*, cardiopulmonary bypass; *ACC*, aortic crossclamp; *ACP*, antegrade cerebral perfusion; *RCP*, retrograde cerebral perfusion; *DHCA*, deep hypothermic cardiac arrest. *Data are presented as median [IQR], or as number (%). †Significantly different between ASC and DST. ‡Significantly different between ASC and PRX. §Significantly different between ASC and D+P. ||Significantly different between DST and PRX. ¶Significantly different between DST and D+P. #Significantly different between PRX and D+P. **No difference in all the comparisons of the 4 groups. ††Significantly different in all the comparisons of the 4 groups.

predictor of eventful postoperative recovery (odds ratio [OR], 10.0; 95% confidence interval [CI], 1.8-189.5), whereas PRX (OR, 2.8; 95% CI, 0.5-52.9) and D+P (OR, 2.7; 95% CI, 0.5-51.3) were not. Chronic kidney disease (OR, 1.8; 95% CI, 1.1-2.7) and CPB time (OR, 1.0; 95% CI, 1.0-1.1) were also shown as other predictors.

The analysis using mixed-effect model with "surgeon" as a random effect showed results consistent with those before using the model (Table E1).

TABLE 3. In-hospital outcomes

Variable*	Overall (n = 1132)	ASC (n = 52)	DST (n = 126)	PRX (n = 620)	D+P (n = 334)	P value
In-hospital mortality	16 (1.4)	1 (1.9)	5 (4.0)	2 (0.3)	8 (2.4)	.003‡,||,#
30-d mortality	17 (1.5)	1 (1.9)	5 (4.0)	3 (0.5)	8 (2.4)	.010‡,||
Stroke	24 (2.1)	1 (1.9)	12 (9.5)	7 (1.1)	4 (1.2)	<.001‡,§,||,¶
Reexploration for bleeding	48 (4.2)	2 (3.8)	3 (2.4)	19 (3.1)	24 (7.2)	.016#
Respiratory failure	87 (7.7)	3 (5.8)	30 (23.8)	26 (4.2)	28 (8.4)	<.001||,¶
Acute renal failure	69 (6.1)	1 (1.9)	9 (7.1)	41 (6.6)	18 (5.4)	.493**
Postcardiotomy shock	13 (1.1)	1 (1.9)	2 (1.6)	6 (1.0)	4 (1.2)	.879**
Deep sternal wound infection	12 (1.1)	0	2 (1.6)	5 (0.8)	5 (1.5)	.598**
Permanent pacemaker implantation	51 (4.5)	0	3 (2.4)	29 (4.7)	19 (5.7)	.179**
Eventful recovery	223 (19.7)	6 (11.5)	46 (36.5)	103 (16.6)	68 (20.4)	<.001†,||,¶
ICU length of stay, d	1.0 [1.0-4.0]	1.0 [1.0-5.0]	8.0 [6.0-13.8]	1.0 [1.0-3.0]	1.0 [1.0-3.0]	<.001||,¶
Hospital length of stay, d	6.0 [5.0-7.0]	6.0 [4.8-8.0]	9.0 [2.0-35.0]	6.0 [5.0-8.0]	6.0 [5.0-9.0]	<.001†,||,¶

ASC, Ascending aortic replacement; *DST*, ascending aortic replacement with distal extension with hemiarch, partial arch, or total arch replacement; *PRX*, ascending aortic replacement with proximal extension with aortic valve replacement or aortic root replacement; *D+P*, ascending aortic replacement with distal and proximal extension; *ICU*, Intensive care unit. *Data are presented as median [IQR] or as number (%). †Significantly different between ASC and DST. ‡Significantly different between ASC and PRX. §Significantly different between ASC and D+P. ||Significantly different between DST and PRX. ¶Significantly different between DST and D+P. #Significantly different between PRX and D+P. **No difference in all the comparisons of the 4 groups.

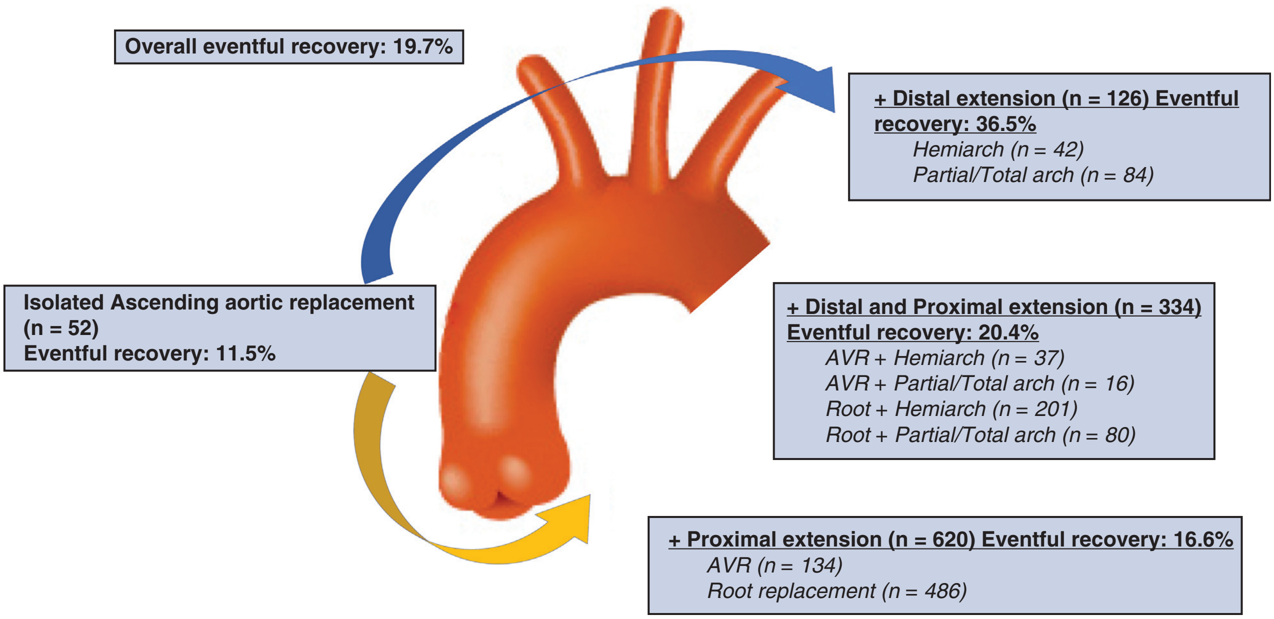

FIGURE 2. Eventful recovery rates by replacement extent after open proximal aortic aneurysm repair. *AVR*, Aortic valve replacement.

Subgroup Analysis of the Distal Extension

Table 5 shows the in-hospital outcomes of patients who underwent distal extension (DST and D+P, n = 460), divided into the hemiarch replacement group (n = 280) and the partial/total arch replacement (n = 180). In-hospital mortality and stroke rates were 1.8% and 2.5% in hemiarch replacement and 4.4% and 5.5% in partial/total arch replacement, respectively (P = .164 and .149).

TABLE 4. Univariable and multivariable logistic regression analysis for eventful recovery

	Univariate		Multivariate	
Variables*	OR (95% CI)	P value	OR (95% CI)	P value
Age	1.02 (1.01-1.03)	<.001†	1.01 (0.99-1.03)	.143
Hypertension	1.41 (1.02-1.98)	.043†	0.95 (0.58-1.58)	.842
Diabetes	1.71 (1.09-2.63)	.016†	1.62 (0.90-2.86)	.100
CVD	1.77 (1.06-2.88)	.025†	0.94 (0.42-1.96)	.882
PAD	1.57 (1.00-2.43)	.049†	1.55 (0.79-2.93)	.190
CKD	2.08 (1.54-2.79)	<.001†	1.77 (1.14-2.75)	.010†
LVEF	0.98 (0.97-0.99)	.013†	0.99 (0.97-1.01)	.157
Previous cardiac surgery	1.73 (1.02-2.84)	.035†	0.87 (0.24-2.59)	.810
Bicuspid aortic valve	0.72 (0.53-0.98)	.041†	1.43 (0.90-2.28)	.129
Size of aortic root	0.98 (0.96-0.99)	.015†	0.98 (0.96-1.01)	.201
Size of aortic arch	1.04 (1.02-1.06)	<.001†	1.00 (0.97-1.03)	.845
Procedure type (reference = ASC)				
DST vs ASC	3.70 (1.87-12.22)	.002†	10.0 (1.79-189.49)	.032†
PRX vs ASC	1.53 (0.68-4.07)	.344	2.84 (0.53-52.88)	.325
D+P vs ASC	1.96 (0.86-5.29)	.139	2.70 (0.48-51.26)	.359
CPB, min	1.01 (1.00-1.01)	<.001	1.01 (1.00-1.02)	.001†
ACC, min	1.01 (1.00-1.01)	.004†	1.00 (0.99-1.01)	.895

In the final model, Hosmer–Lemeshow = 0.506; c-statistic = 0.711. *CI*, Confidence interval; *OR*, odds ratio; *CVD*, cerebrovascular disease; *ACC*, aortic crossclamp; *PAD*, peripheral artery disease; *CKD*, chronic kidney disease; *LVEF*, left ventricular ejection fraction; *ASC*, ascending aortic replacement; *DST*, ascending aortic replacement with distal extension with hemiarch, partial arch, or total arch replacement; *PRX*, ascending aortic replacement with proximal extension with aortic valve replacement or aortic root replacement; *CPB*, cardiopulmonary bypass; *D+P*, ascending aortic replacement with distal and proximal extension. *Variables with $P < .1$ in univariable analysis were included in multivariable analysis. †Statistically significant ($P < .050$).

TABLE 5. Postoperative outcomes in patients with ascending aortic replacement with distal extension with hemiarch, partial arch, or total arch replacement and ascending aortic replacement with distal and proximal extension

Variable*	Hemiarch replacement (n = 280)	Partial/total arch replacement (n = 180)	*P* value
In-hospital mortality	5 (1.8)	8 (4.4)	.164
30-d mortality	5 (1.8)	8 (4.4)	.166
Stroke	7 (2.5)	10 (5.6)	.149
Reexploration for bleeding	17 (6.1)	10 (5.6)	.979
Respiratory failure	29 (10.4)	29 (16.1)	.095
Acute renal failure	14 (5.0)	13 (7.2)	.432
Postcardiotomy shock	3 (1.1)	3 (1.7)	.898
Deep sternal wound infection	3 (1.1)	4 (2.1)	.553
Permanent pacemaker implantation	15 (5.4)	7 (3.9)	.620
Eventful recovery	61 (21.8)	53 (29.4)	.081
ICU length of stay, d	1.0 [1.0-3.0]	2.0 [1.0-10.0]	<.001
Hospital length of stay, d	6.0 [5.0-9.0]	8.0 [5.0-10.0]	<.001

ICU, Intensive care unit. *Statistically significant ($P < .050$).

There was no significant difference in the rate of eventful recovery between hemiarch replacement (21.8%) and partial/total arch replacement (29.4%).

In the multivariable analysis for failure to uneventful recovery using hemiarch replacement as a reference, the adjusted OR of partial/total arch replacement was 0.8 (95% CI, 0.5-1.4), whereas it was 2.9 (95% CI, 1.2-6.8) in the analysis for hard end point including in-hospital mortality and stroke (Table 6).

DISCUSSION

The present study shows the contemporary outcomes of open proximal aortic aneurysm repair: In-hospital mortality is low with approximately 80% of uneventful recovery rate. Distal extension of aortic procedure is independently associated with higher complication rate, whereas proximal extension is not. This is the first large cohort study to examine the association between the extension of the aortic replacement and the outcome, providing important confirmatory evidence to the literature and useful clinical guidance to surgeons in deciding on the procedural type that matches the expected risk profile of individual patients. Furthermore, it provides preliminary data for future development of risk model in proximal aortic surgery.

We hypothesized that procedural type is an important factor on the outcome of thoracic aortic surgery. Our data suggest that more extensive procedures are associated with a higher complication rate. Eventful recovery after proximal aortic aneurysm repair occurred more frequently as more procedures were added to isolated ascending replacement. This was particularly significant with distal extension. Although our hypothesis and these observations have mechanical plausibility, existing literature is contradictory. Several reports claimed that addition of a hemiarch replacement to ascending aorta or aortic root replacement does not adversely affect postoperative outcomes. Sultan

TABLE 6. Independent predictors of eventful recovery and combined end point of mortality or stroke in patients with ascending aortic replacement with distal extension with hemiarch, partial arch, or total arch replacement and ascending aortic replacement with distal and proximal extension

	Failure to uneventful recovery		Mortality or stroke	
Variable	OR (95% CI)	*P* value	OR (95% CI)	*P* value
Diabetes	2.06 (1.01-4.22)	.048†	4.19 (1.65-10.6)	.003†
CKD	2.06 (1.21-3.52)	.008†	1.08 (0.47-2.49)	.852
LVEF	0.96 (0.94-0.99)	.008†	0.99 (0.95-1.03)	.306
Proximal extension	0.35 (0.18-0.67)	.002†	- (-)	-
Partial/total arch replacement (vs hemiarch replacement)	0.81 (0.46-1.40)	.444	2.91 (1.25-6.78)	.013†
CPB, min	1.01 (1.00-1.02)	<.001†	1.00 (0.99-1.01)	.579

In the final model, Hosmer–Lemeshow = 0.735 and 0.713; c-statistic = 0.714 and 0.712 in each outcome. *CI*, Confidence interval; *OR*, odds ratio; *CKD*, chronic kidney disease; *LVEF*, left ventricular ejection fraction; *CPB*, cardiopulmonary bypass. *Variables with $P < .1$ in univariable analysis were included into multivariable analysis. †Statistically significant ($P < .050$).

and colleagues[23] compared 116 patients each (propensity score matched) who underwent ascending aortic replacement with or without additional hemiarch replacement for aortic aneurysm and reported no significant differences in postoperative stroke, new postoperative dialysis, postoperative renal insufficiency, and 30-day mortality. Preventza and colleagues[24] showed similar findings in their 140 patients. An analysis of the ARCH database, including 1169 patients who underwent elective aortic arch replacement, showed that the additional of root replacement during aortic arch replacement did not increase postoperative morbidity and mortality.[25] On the other hand, we have reported that the addition of a hemiarch replacement in patients with a proximal aortic aneurysm has a negative impact on outcomes.[26] Hage and colleagues[27] also showed that the addition of aortic root manipulation to arch repair increased mortality and reoperation for bleeding.

The present study is characterized by its large cohort size and use of a unique end point, eventful recovery. Together, our dataset allowed robust, comprehensive, and relevant assessment of the influence of the procedural type on the chosen outcomes. In the context of improvement in the conventional clinical end points, such as in-hospital mortality or stroke, patients seem to be increasingly interested in expedited recovery after aneurysm repair. Eventful recovery was an outcome measure of a combined end points. Our previous study showed that eventful recovery was associated with not only prolonged hospital stay but also long-term survival after aortic root replacement.[15] Overall, eventful recovery occurred in approximately 20% of our cohort. The multivariable logistic regression analysis for the primary end point, eventful recovery, showed an OR of 10.0 for distal extension and 2.8 for proximal extension, compared with isolated ascending aortic replacement, supporting our hypothesis. Furthermore, partial or total arch replacement had an OR of 2.9 for a combined end point of in-hospital mortality and stroke when compared with hemiarch replacement, again in line with our hypothesis. This study informs clinicians to be mindful of the fact that extension of aortic replacement influences short-term outcomes; however, the data should not be interpreted as a suggestion to minimize the extension of the replacement. Instead, the risk associated with the aortic replacement should be balanced against the prediction of the future risk of the aortic event for individual patients.

Study Limitations

There are several limitations in the present study. The findings from this retrospective single center study may not be generalizable. Although the study included one of the largest numbers of patients for this topic, the sample size, especially the small number in the reference procedure, isolated ascending aortic replacement, precludes further in-depth analysis, such as comparing outcomes between partial arch and total arch replacement. Additionally, our sample size leads to the wide CI in the multivariable model, especially for the procedure types, calling for caution in data interpretation. Finally, although we included as many variables as possible in the model, the analytic results may be influenced by unmeasured biases. Expert surgeons make decisions often qualitatively (or subjectively) influenced by collective interpretation of preoperative or intraoperative factors, which are not necessarily included in the database, or based on the "eyeball test." Furthermore, the quality of the aorta, such as friable tissue and degree of atherosclerosis, could not be addressed. These unmeasured confounders are likely responsible for our observation that D+P patients had more encouraging results than DST patients. In this study, the variable selection for the multivariable model based on the literature review and statistical results. The model was validated using the Hosmer–Lemeshow goodness-of-fit test and c-statistic. The results showed evidence of good fit.

CONCLUSIONS

This study confirmed that thoracic aortic surgery is not uniform while demonstrating overall low mortality and some recognizable complication rates of proximal thoracic aortic aneurysm repair in the contemporary era. It showed the association between the extension of the aortic replacement and the rate of complications. The data suggest a key role of procedural type in developing risk assessment models as well as recommendations for surgical repair of aneurysm.

Webcast

You can watch a Webcast of this AATS meeting presentation by going to: https://aats.blob.core.windows.net/media/21%20AM/Abstracts_Discussions/77.%20Open%20Proximal%20Aortic%20Aneurysm%20Repair%20In%20Contemporary%20Era.mp4.

Conflict of Interest Statement

The authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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Key Words: aortic aneurysm, aortic arch replacement, aortic root replacement, extent of aortic replacement, hemiarch replacement, open proximal thoracic aortic repair, procedure type

Discussion

Presenter: Dr Hiroo Takayama

Unidentified Speaker 1. Okay, the invited discussant for this is going to be Maral Ouzounian.

Dr Maral Ouzounian *(Toronto, Canada)*. It's my privilege to discuss this paper today. Your group has reported the early results of more than 1100 patients undergoing elective proximal aortic repair at Columbia University over a 15-year period. Results were excellent, with an overall mortality of 1.5% and stroke of 2%, although the risk of death and stroke increased to 4% and 9.5% respectively in the distal extension group. Partial or total arch replacement was associated with a 2.9-fold increased risk of death or stroke on multivariable analysis. I would like to congratulate the authors for reporting the contemporary results of elective proximal aortic repair at a tertiary care center. They wisely excluded acute dissections, endocarditis, emergency procedures, and concomitant surgery other than aortic valve interventions. By keeping the study cohort fairly homogenous, they have highlighted the outcomes after elective isolated proximal aortic repair and the independent predictors of adverse events. I also appreciated that they looked not only at stroke and death but also at a composite end point of adverse events after surgery.

I have a few questions for Dr Takayama. I'll start with the most striking finding, that proximal extension into the root was not associated with increased risk, but distal extension was. This finding contradicts previous reports in the literature by several groups who found no increased risk with the addition of a hemiarch procedure. Intuitively, adding a total arch to a root replacement would increase perioperative risk, but your proximal and distal combined group had a very low rate of adverse events. So what do you think accounts for this increased risk with distal extension aortic repair in your study compared to other reports in the literature? You did not report circulatory rest times or nadir temperatures at which circulatory rest were performed. Were these accounted for in the analysis? Did patients undergoing a total arch replacement receive bilateral ACP? Perhaps you could hypothesize as to why this increased risk was observed and briefly describe your approach to brain protection and how it has evolved over the years.

Dr Hiroo Takayama *(New York, NY)*. Thank you Dr Ouzounian for closely examining our abstract while you are extremely busy taking care of your patients with Coronavirus Disease 2019 in your hometown, Toronto. Your questions are to the point. We totally agree with you that some of our findings are actually surprising to us as well because the previous literature shows that adding at least hemiarch does not really change the risk. I think, however, our study is uniquely equipped with a strength over the previous studies because we have a larger sample, and event rates are higher because we chose these combined end points. Together, I think—no, we believe it allowed identifying a small, but important, significant difference. Clinically, it's an important difference among the procedures. Also, as to the reason of this worse outcome in the distal group, which is perplexing, I must admit that it seems to make sense that the larger operation results in worse outcome. We cannot agree more that examining the detail of these arch procedures in an attempt to understand why this outcome is worse is critical. For this study, we did not account for the variables associated with circulatory rest or cerebral protections because these measures are not available from the arch replacement, and therefore, the collinearity was too much for the further statistical analysis. Just briefly talking about our strategy for the arch surgery, we don't routinely check the circulatory rest. And hemiarch is typically performed with unilateral cerebral protection, and total arch is usually with bilateral. Both are usually with moderate [inaudible]. In earlier years, we used to use axillary cannulation, but now we more frequently use central cannulation.

Unidentified Speaker 1. It was a great response, but in addition to what Maral pointed out having to do with mortality and stroke, in your distal extensions, you also had a significantly increased respiratory failure problem. I was wondering if you looked into issues that are associated with that in arch replacement such as recurrent laryngeal nerve and blood transfusion.

Dr Takayama. That's an excellent point. Again, we couldn't really separate out the reason for that, but certainly, many of our composite end points—difference of our primary end points, which is composite end points, the differences are driven by mostly respiratory failure and acute renal injury. I totally agree that the prolonged ventilator time is the problem of these arch procedures compared with the root or ascending, and as you pointed out, the mechanical issues that are unique to the arch surgery, such as recurrent laryngeal nerve. We are doing a separate project examining those mechanically important complications uniquely associated with arch surgery. In that preliminary data analysis, we didn't find a difference, for instance, vocal cord injury or prolonged ventilation due to phrenic nerve or paralyzed diaphragm and so forth. Instead, what we found was that, simply, these patients are on the ventilator for a longer period of time. Perhaps that's related to the nature of circulatory rest, at least in our hands. Or we are wondering whether that may be related to the fact that other, more routine [inaudible] patients, if they are ascending or root patients, are treated similar to coronary artery bypass grafting valve patients under the fast track.

Unidentified Speaker 1. I'd be interested and look forward to your further analysis to sort out whether it's a technical problem or if it's a patient selection comorbidity issue. But to stay on time, we have to move on.

TABLE E1. Multivariable logistic regression analysis for eventful recovery using mixed-effect model with surgeon as a random effect

Fixed effects	OR (95% CI)	*P* value
Age	1.01 (0.99-1.03)	.144
Hypertension	0.95 (0.58-1.57)	.842
Diabetes	1.62 (0.91-2.89)	.101
CVD	0.94 (0.44-2.02)	.882
PAD	1.55 (0.80-2.97)	.191
CKD	1.77 (1.14-2.74)	.011*
LVEF	0.99 (0.97-1.01)	.157
Previous cardiac surgery	0.87 (0.27-2.78)	.810
Bicuspid aortic valve	1.43 (0.90-2.27)	.129
Size of aortic root	0.98 (0.96-1.01)	.201
Size of aortic arch	0.99 (0.97-1.03)	.845
Procedure type (reference = ASC)		
DST vs ASC	10.0 (1.21-83.15)	.033*
PRX vs ASC	2.84 (0.35-22.84)	.326
D+P vs ASC	2.67 (0.32-22.58)	.359
CPB, min	1.01 (1.00-1.02)	.01*
ACC, min	0.99 (0.99-1.01)	.895

CI, Confidence interval; *OR*, odds ratio; *CVD*, cerebrovascular disease; *PAD*, peripheral artery disease; *CKD*, chronic kidney disease; *LVEF*, left ventricular ejection fraction; *ASC*, open thoracic aortic aneurysm repair undergoing isolated ascending aortic replacement; *DST*, partial arch or total arch replacement; *CPB*, cardiopulmonary bypass; *ACC*, aortic crossclamp; *PRX*, ascending + aortic valve replacement or aortic root replacement. *Statistically significant ($P < .050$).