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Cardiac Surgery

# Contemporary Results for Proximal Aortic Replacement in North America

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**Objectives** The purpose of this study was to characterize operative outcomes for ascending aorta and arch replacement on a national scale and to develop risk models for mortality and major morbidity.

**Background** Contemporary outcomes for ascending aorta and arch replacement in North America are unknown.

**Methods** We queried the Society of Thoracic Surgeons Database for patients undergoing ascending aorta (with or without root) with or without arch replacement from 2004 to 2009. The database captured 45,894 cases, including 12,702 root, 22,048 supracoronary ascending alone, 6,786 ascending plus arch, and 4,358 root plus arch. Baseline characteristics and clinical outcomes were analyzed. A parsimonious multivariable logistic regression model was constructed to predict risks of mortality and major morbidity.

**Results** Operative mortality was 3.4% for elective cases and 15.4% for nonelective cases. A risk model for operative mortality (c-index 0.81) revealed a risk-adjusted odds ratio for death after emergent versus elective operation of 5.9 (95% confidence interval: 5.3 to 6.6). Among elective patients, end-stage renal disease and reoperative status were the strongest predictors of mortality (adjusted odds ratios: 4.0 [95% confidence interval: 2.6 to 6.4] and 2.3 (95% confidence interval: 1.9 to 2.7], respectively; $p < 0.0001$).

**Conclusions** Current outcomes for ascending aorta and arch replacement in North America are excellent for elective repair; however, results deteriorate for nonelective status, suggesting that increased screening and/or lowering thresholds for elective intervention could potentially improve outcomes. The predictive models presented may serve clinicians in counseling patients. (J Am Coll Cardiol 2012;60:1156–62) © 2012 by the American College of Cardiology Foundation

Despite the development of improved operative techniques and circulatory adjuncts, existing published data suggest that ascending aortic and arch repairs retain significant morbidity and mortality (1). However, the best clinical studies suffer important limitations, including single-institution reporting, small sample sizes, and operative techniques no longer commonly in use. Thus, the objectives of this study are: 1) to report the characteristics and outcomes of patients undergoing ascending aortic and arch replacement in a large contemporaneous North American cohort; and 2) to determine the predictors of mortality and major morbidity for these patients.

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## Methods

**Data source.** The Society of Thoracic Surgeons (STS) Adult Cardiac Surgery Database (ACSD) currently houses data from >950 participants, representing >90% of the cardiac surgery centers in the United States. Clinical sites enter data using uniform definitions. The quality of the data has been rigorously assessed by comparison with independent national and regional datasets (2). The present study was approved by the Access and Publications Committee of the STS Workforce for National Databases as well as by the Duke University institutional review board.

**Patient population.** The study population consists of all patients with aortic pathology requiring repair of the ascending aorta (with or without root) with or without arch reported to the STS ACSD between 2004 and 2009.

Patients undergoing descending or thoracoabdominal aortic replacement were not included. The STS ACSD first began distinguishing aortic replacement location (ascending, arch, descending, and thoracoabdominal) in 2004, with implementation of case report form version 2.52, and the current analysis was based on this form.

**Data collection and definitions.** Those variables previously identified in the peer-reviewed literature as potential predictors of outcome in aortic surgery were included as candidate variables for the analysis, as well as all variables from existing STS 30-day operative mortality and morbidity risk models (3). Data regarding maximal aortic diameter, use of circulatory arrest or adjunctive cerebral perfusion, connective tissue disorders, and specifics of intraoperative neuromonitoring were not available for study.

The primary outcome variable was operative mortality, defined as death from any cause either in-hospital or within 30 days of the index thoracic aortic operation. The secondary outcome variable was the composite endpoint of operative mortality and major morbidity, where major morbidity was defined using the standard STS database composite of stroke, renal failure, prolonged ventilation, deep sternal wound infection, and reoperation. Further details regarding STS ACSD data definitions are available online.

**Statistical analysis.** Baseline patient characteristics and outcomes were summarized by percentage distribution for categorical variables and by medians and 25th to 75th percentiles for continuous variables. Missing data were rare (<0.5% for all variables). Missing values of body mass index were imputed to sex-specific median values. Missing values of ejection fraction were imputed to sex-specific median values for patients with congestive heart failure; otherwise, were imputed to 50%. Missing values of remaining risk factors and various outcomes were defaulted to their most common value.

Logistic regression modeling was used to estimate the risk of the individual outcome as a function of patient variables. Models were created for the overall study cohort in addition to the subset of elective patients. Generalized estimating equations methodology was used to fit the models (4); and C statistics were calculated and compared for full and reduced models. For either mortality or major morbidity and mortality, a reduced model was able to explain approximately 99% of the variation in the predicted log odds as estimated by the full model. Full and reduced models were fit again in the overall population to obtain the risk adjusted odds ratios (OR) for predictors.

## Results

**Centers performing proximal aortic replacement.** In 2004, the first year the STS ACSD began recording the location for aortic replacement, 285 North American centers reported 2,121 proximal (ascending with or without arch) aortic replacements. By 2008, 806 participating centers reported 11,033 cases. Figure 1A shows proximal aortic cases captured per year in the STS ACSD. Figure 1B displays the proportion of STS ACSD centers performing proximal aortic replacement and the median number of cases reported per center performing the procedure each year. While the proportion of centers performing proximal aortic replacement increased each year, the number of proxi-

**Abbreviations and Acronyms**

CABG = coronary artery bypass graft surgery

CI = confidence interval

NCSD = National Cardiac Surgery Database

OR = odds ratio

STS = The Society of Thoracic Surgeons

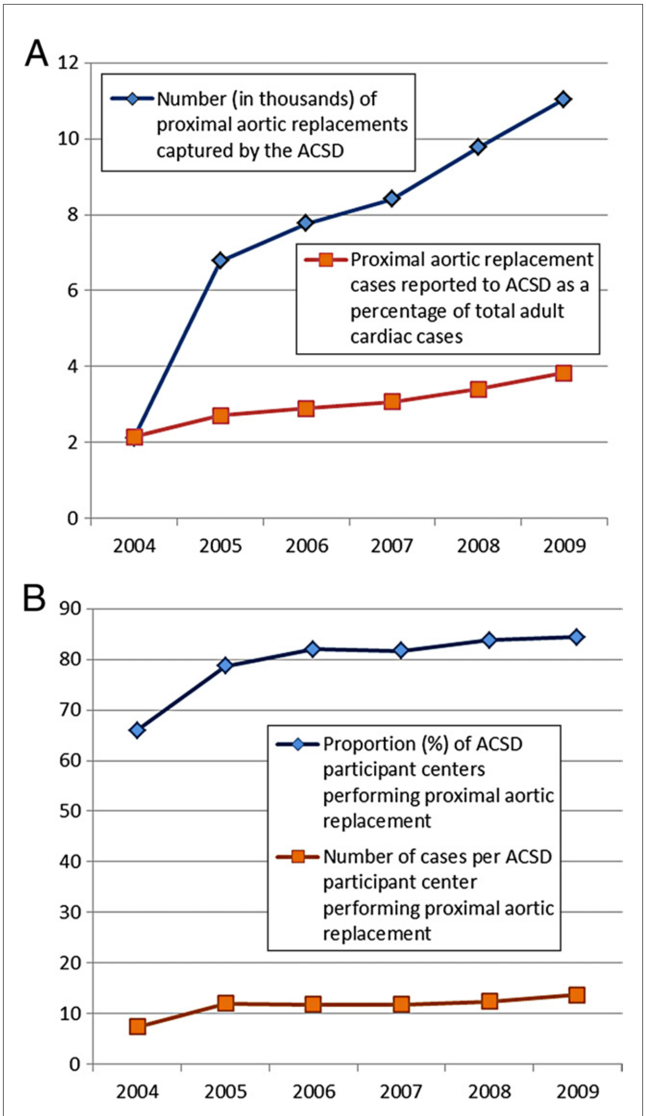


**Figure 1** **Proximal Aortic Replacements Among STS ACSD Participants by Year**

Proximal aortic replacements among The Society of Thoracic Surgeons Adult Cardiac Surgery Database (STS ACSD) participants by year 2004 to 2009. **(A)** Total number of proximal aortic cases captured **(blue line)** per year by the STS ACSD and proximal aortic cases as a percentage of total adult cardiac surgery cases **(red line)** reported to the ACSD each year. **(B)** Proportion of ACSD participant centers reporting proximal aortic procedures **(blue line)** and mean number of cases per reporting center **(red line)**.

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**Table 1 Patient and Operative Characteristics**

| | Proximal Aortic Replacement | | | | |
|---|---|---|---|---|---|
| Characteristics | Overall (N = 45,894) | Root (n = 12,702) | Ascending Alone (n = 22,048) | Ascending + Arch (n = 6,786) | Root + Arch (n = 4,358) |
| Age, yrs | 62 (52–72) | 58 (48–69) | 64 (54–73) | 65 (54–74) | 60 (49–70) |
| Female | 32.09 | 24.85 | 34.30 | 39.95 | 29.78 |
| Race | | | | | |
| Caucasian | 85.19 | 87.34 | 84.85 | 81.27 | 86.78 |
| Black | 7.61 | 6.04 | 7.61 | 10.86 | 7.11 |
| Asian | 2.00 | 1.49 | 2.14 | 2.58 | 1.88 |
| Native American | 0.15 | 0.15 | 0.15 | 0.15 | 0.16 |
| Demographic region | | | | | |
| Midwest | 33.90 | 35.73 | 32.20 | 34.00 | 37.06 |
| Northeast | 20.22 | 17.62 | 18.08 | 26.32 | 29.07 |
| South | 27.10 | 26.29 | 30.25 | 23.90 | 18.52 |
| West | 18.78 | 20.37 | 19.46 | 15.78 | 15.35 |
| Body mass index, kg/m$^2$ | 28 (24–31) | 28 (25–31) | 28 (25–32) | 27 (24–31) | 27 (24–31) |
| Hypertension | 72.41 | 66.01 | 74.74 | 78.79 | 69.32 |
| Current or recent smoker | 21.10 | 19.34 | 21.48 | 24.42 | 19.14 |
| Hypercholesterolemia | 49.19 | 47.43 | 51.10 | 48.17 | 46.21 |
| Chronic lung disease | 17.77 | 16.16 | 18.54 | 19.16 | 16.38 |
| Renal function stages | | | | | |
| GFR ≥90 ml/min/1.73 m$^2$ | 23.30 | 27.20 | 21.84 | 20.76 | 23.29 |
| GFR 60–89 ml/min/1.73 m$^2$ | 51.81 | 52.50 | 51.76 | 48.84 | 54.64 |
| GFR 30–59 ml/min/1.73 m$^2$ | 22.04 | 17.98 | 23.34 | 26.92 | 19.69 |
| GFR ≤29 ml/min/1.73 m$^2$ | 1.65 | 1.32 | 1.79 | 2.08 | 1.24 |
| Dialysis | 1.20 | 0.99 | 1.27 | 1.40 | 1.15 |
| Immunosuppressive treatment | 2.77 | 2.31 | 2.70 | 3.51 | 3.33 |
| Diabetes mellitus | 12.00 | 10.00 | 13.00 | 11.00 | 9.00 |
| Peripheral vascular disease | 19.36 | 16.74 | 19.34 | 23.74 | 20.24 |
| Cerebrovascular disease | 11.28 | 8.88 | 11.74 | 14.44 | 11.06 |
| History of myocardial infarction | 11.43 | 9.23 | 13.35 | 11.11 | 8.65 |
| History of congestive heart failure | 20.01 | 22.40 | 19.58 | 15.38 | 22.44 |
| Any previous cardiovascular surgery | 16.69 | 16.11 | 15.67 | 19.19 | 19.62 |
| Previous CABG | 5.38 | 3.92 | 6.30 | 5.78 | 4.31 |
| Previous valve procedure | 10.28 | 10.97 | 9.36 | 10.36 | 12.76 |
| Pre-operative cardiogenic shock | 3.91 | 2.50 | 4.21 | 5.94 | 3.30 |
| Procedure status | | | | | |
| Elective | 59.22 | 70.11 | 55.53 | 47.27 | 64.80 |
| Urgent | 20.46 | 19.03 | 21.69 | 20.07 | 18.95 |
| Emergent | 19.19 | 10.16 | 21.55 | 30.78 | 15.53 |
| Salvage | 1.08 | 0.66 | 1.17 | 1.83 | 0.71 |
| Urgent reason | | | | | |
| Anatomy | 29.52 | 23.71 | 33.43 | 30.54 | 22.15 |
| Aortic dissection | 24.74 | 14.36 | 22.56 | 47.36 | 30.51 |
| Valve dysfunction | 23.53 | 38.68 | 20.13 | 8.00 | 24.46 |
| Congestive heart failure | 11.44 | 15.60 | 10.01 | 5.73 | 16.95 |
| Emergent reason | | | | | |
| Aortic dissection | 93.87 | 89.54 | 93.92 | 96.17 | 94.68 |
| Shock | 2.1 | 2.8 | 2.0 | 1.5 | 2.5 |
| Valve dysfunction | 1.39 | 4.65 | 0.86 | 0.53 | 1.48 |
| Concomitant CABG | 25.94 | 24.50 | 28.83 | 21.19 | 22.85 |
| Concomitant mitral valve procedure | 7.2 | 5.0 | 9.4 | 6.3 | 4.8 |
| Concomitant arrhythmia correction | 4.97 | 5.53 | 5.45 | 3.04 | 3.85 |
| Operation time, h | 5.2 (4.1–6.6) | 5.2 (4.2–6.7) | 4.8 (3.7–6.1) | 5.7 (4.6–7.1) | 6.2 (4.9–7.7) |
| Cross-clamp time, min | 111 (79–152) | 131 (101–170) | 95 (67–129) | 102 (70–141) | 154 (118–197) |

Values are median (25th to 75th percentiles) or %.
CABG = coronary artery bypass graft surgery; GFR = glomerular filtration rate.

mal aortic replacements per center remained relatively constant at approximately 12 cases per center.

**Patient and operative characteristics.** Table 1 displays patient demographics for the overall cohort stratified by location of aortic replacement. As a whole, patients undergoing supracoronary ascending aortic replacement with or without arch were older and had more comorbid conditions. Overall, 59% of cases were elective, 20% urgent, and 20% emergent. For emergent cases, aortic dissection was the indication 94% of the time. Supracoronary ascending with or without arch procedures were most common in the nonelective setting, with >50% of ascending plus arch cases being nonelective. The addition of arch replacement to ascending aortic or root replacement increased cross-clamp time and operative time modestly.

**Clinical outcomes.** Figure 2 displays operative mortality stratified by case status. Table 2 shows univariate outcomes for the overall proximal aortic population, stratified by location of aortic repair and elective versus nonelective case status. Overall operative mortality was 8.3%, including 3.4% for elective and 15.4% for nonelective cases. Mortality was highest for nonelective supracoronary ascending plus arch replacement, at 17.6%.

Nonfatal adverse outcomes included stroke or coma in 6.6% of patients, renal failure in 8.3%, perioperative myocardial infarction in 2.4%, and prolonged ventilation in 27.8%. Similar to mortality, stroke rate was highest for cases involving replacement of the supracoronary ascending aorta and arch (Table 2). Adverse outcomes were more common after nonelective operation, with the exception of perioperative myocardial infarction which occurred with similar frequency after elective and nonelective operation.

**Predictive models.** Table 3 displays predictors in the reduced model for operative mortality after proximal aortic replacement (c-index 0.82). The risk-adjusted OR for death after emergent versus elective operation was 5.9 (95% confidence interval [CI]: 5.3 to 6.6; $p < 0.0001$]. Concomitant coronary artery bypass graft surgery (CABG [adjusted OR: 2.1]) or mitral valve procedure (adjusted OR: 1.6) each conferred significantly higher risk of death. Adjusted OR for mortality with arch involvement was 1.2 (95% CI: 1.1 to 1.4; $p = 0.0002$). However, the adjusted OR for root involvement was 1.0 (95% CI: 0.9 to 1.1; $p = 0.72$) in the full model and did not remain in the reduced model. Table 4 displays results of the multivariable model for major morbidity or mortality (c-index 0.78), with results of the predictive model being similar to the operative mortality model.

Table 5 displays predictors of operative mortality among patients undergoing elective operation (c-index 0.77). Among elective patients, end-stage renal disease (preoperative dialysis) was the strongest predictor of mortality, with adjusted OR 4.0 (95% CI: 2.6, 6.4; $p < 0.0001$). For patients undergoing reoperation (any redo sternotomy), adjusted OR for mortality was 2.3 (95% CI: 1.9 to 2.7; $p < 0.0001$). Predictors of major morbidity and mortality among elective patients are presented in Table 6 (c-index 0.71), with results of the predictive model again similar to those of the operative mortality model.

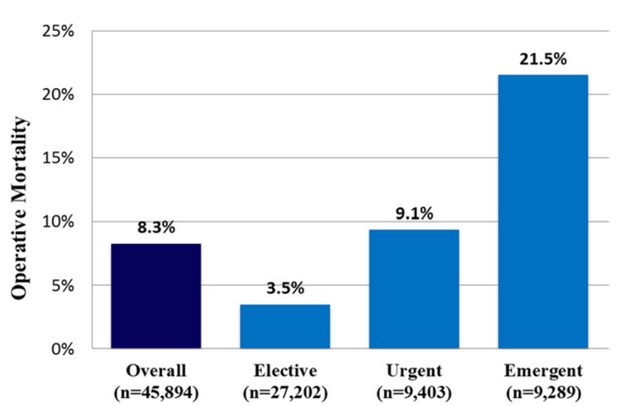


**Figure 2** **Operative Mortality**

Operative mortality, defined as death from any cause either in-hospital or within 30 days of the index thoracic aortic operation, categorized by procedure status.

## Discussion

The present study provides a broad overview of the current practice and outcomes for proximal aortic replacement in North America. The 45,894 patients captured in the STS ACSD between 2004 and 2009 represent the largest contemporaneous cohort of proximal aortic replacement reported to date. The elective mortality of 3.4% is excellent; however, results markedly deteriorate for nonelective status, and the overall operative mortality of 8.3% and stroke rate of 6.6% indicate room for continued improvement. The multivariable models predicting mortality and major morbidity confirm the critical prognostic importance of procedure status: adjusted OR 5.9 and 2.0, respectively, for operative death with emergent and urgent operation, versus elective cases. Arch involvement was associated with increased risk of mortality and major morbidity; however, root involvement was not. Adverse outcomes appeared more common after supracoronary ascending (with or without arch) replacement, despite being technically less challenging than root replacement, in both elective and nonelective settings, likely secondary to the older age and greater comorbidities of these patients. Among the subset of elective patients, severe renal dysfunction, reoperation status, severe lung disease, and concomitant procedures are the strongest predictors of operative mortality and major morbidity.

While the morbidity and mortality associated with thoracic aortic repair remain high relative to other surgical procedures, patient outcomes have improved in each of the past 3 decades due in part to advances in operative approaches, perioperative care, and increased surveillance (4–6). Single-institution studies from aortic surgery referral centers

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**Table 2 Unadjusted Event Rates**

| | Proximal Aortic Replacement | | | | |
|---|---|---|---|---|---|
| Outcome | Overall (N = 45,894) | Root (n = 12,702) | Ascending Alone (n = 22,048) | Ascending + Arch (n = 6,786) | Root + Arch (n = 4,358) |
| Operative mortality, in-hospital or 30-day | 8.28 | 6.01 | 8.67 | 11.67 | 7.62 |
| Elective | 3.36 | 2.72 | 3.41 | 5.05 | 3.29 |
| Nonelective | 15.42 | 13.74 | 15.25 | 17.62 | 15.58 |
| Stroke >72 h or coma >24 h | 6.62 | 3.92 | 6.88 | 11.03 | 6.29 |
| Elective | 3.17 | 2.24 | 3.24 | 5.33 | 3.36 |
| Nonelective | 9.84 | 6.91 | 9.83 | 13.09 | 9.58 |
| Renal failure | 8.31 | 6.27 | 8.45 | 11.54 | 8.56 |
| Elective | 4.41 | 3.91 | 4.22 | 6.07 | 4.96 |
| Nonelective | 14.00 | 11.84 | 13.75 | 16.45 | 15.19 |
| Dialysis | 3.86 | 2.83 | 3.81 | 5.92 | 3.88 |
| Elective | 1.68 | 1.36 | 1.57 | 2.83 | 1.91 |
| Nonelective | 7.02 | 6.28 | 6.63 | 8.70 | 7.50 |
| Perioperative MI | 2.39 | 1.96 | 2.53 | 3.27 | 2.80 |
| Elective | 2.48 | 2.47 | 2.01 | 3.89 | 2.94 |
| Nonelective | 2.26 | 2.66 | 1.90 | 2.71 | 2.54 |
| Pneumonia | 6.65 | 4.48 | 6.82 | 9.80 | 7.25 |
| Elective | 4.12 | 3.04 | 4.06 | 6.45 | 5.10 |
| Nonelective | 10.34 | 7.86 | 10.26 | 12.81 | 11.21 |
| Deep sternal wound infection | 0.58 | 0.60 | 0.48 | 0.75 | 0.48 |
| Elective | 0.45 | 0.36 | 0.52 | 0.59 | 0.28 |
| Nonelective | 0.76 | 0.76 | 0.69 | 0.90 | 0.85 |
| Reoperation for bleeding | 7.39 | 7.13 | 7.16 | 8.27 | 7.89 |
| Elective | 5.68 | 5.70 | 5.34 | 6.23 | 6.41 |
| Nonelective | 9.88 | 10.50 | 9.44 | 10.10 | 10.63 |
| Any reoperation | 14.22 | 12.73 | 13.81 | 17.89 | 14.96 |
| Elective | 10.09 | 9.56 | 9.47 | 12.71 | 11.44 |
| Nonelective | 20.24 | 20.17 | 19.23 | 22.55 | 21.45 |
| Prolonged ventilation >24 h | 27.81 | 20.22 | 27.99 | 40.44 | 29.39 |
| Elective | 16.23 | 12.79 | 15.49 | 25.97 | 19.23 |
| Nonelective | 44.66 | 37.66 | 43.63 | 53.43 | 48.11 |
| Post-operative length of stay >14 days | 15.73 | 16.12 | 11.23 | 22.90 | 15.72 |
| Elective | 9.31 | 7.05 | 9.28 | 14.82 | 10.27 |
| Nonelective | 25.08 | 21.07 | 24.68 | 30.15 | 25.75 |

Values are %.
MI = myocardial infarction.

have reported in-hospital mortality ranging from 3% to 8%, 30-day mortality from 5% to 10%, stroke from 3% to 6%, and renal failure from 2% to 10% (7–9). The findings of the present study indicate comparable results among STS ACSD participating centers.

Although an increasing number of proximal aortic replacement cases were reported to the STS ACSD during each year of study, the median number of cases per participant doing at least 1 case has risen only slightly, with the 2008 average being only 12 cases per participating center. A recent study analyzing the effects of institutional volumes on operative outcomes for aortic root replacement in North America using the STS ACSD found a clear, inverse association between hospital procedure volume and post-operative mortality, which appeared most pronounced among centers performing fewer than 30 to 40 elective aortic root procedures per year (10). Recent data from 2,218 CABG patients, however, has found that outcomes did not vary significantly based on volume but instead were correlated with compliance with National Quality Forum process measures (11). This finding suggests an opportunity for further systems analysis aimed at optimizing quality of care for patients requiring proximal aortic replacement by examining the role of volume and other processes of care in thoracic aortic surgery.

The risk models presented herein may assist clinicians in risk stratification and patient counseling when planning proximal aortic replacement. Urgent/emergent procedure status, reoperation, chronic renal failure, and pulmonary disease have each been associated with adverse outcomes in smaller observational studies of ascending and aortic arch repair (1,8,9) and are corroborated by the results of the

**Table 3 Selected Predictors of Operative Mortality Among All Patients**

| Variable | Adjusted OR (95% CI) | p Value |
|---|---|---|
| Status: emergent vs. elective | 5.91 (5.31–6.58) | <0.0001 |
| Pre-operative shock | 2.01 (1.74–2.31) | <0.0001 |
| Status: urgent vs. elective | 2.01 (1.78–2.27) | <0.0001 |
| Concomitant CABG | 2.14 (1.87–2.46) | <0.0001 |
| Concomitant mitral valve procedure | 1.63 (1.36–1.96) | <0.0001 |
| Any reoperation | 1.63 (1.43–1.86) | <0.0001 |
| Cerebrovascular disease | 1.43 (1.28–1.59) | <0.0001 |
| Chronic kidney disease stage 3 or greater, GFR <60 ml/min/1.73 $m^2$ | 1.43 (1.32–1.56) | <0.0001 |
| Moderate or severe chronic lung disease | 1.36 (1.20–1.54) | <0.0001 |
| Arch involvement | 1.23 (1.10–1.37) | 0.0002 |

CI = confidence interval; OR = odds ratio; other abbreviations as in Table 1.

present analysis. Performance of concurrent CABG or mitral valve procedure was shown to increase risk for mortality and major morbidity among the overall study cohort (Tables 3 and 4) as well as the subset of elective patients (Tables 5 and 6). In addition, concomitant arch replacement was associated with an increased risk for adverse outcomes in all models, but root replacement was not. For the clinician counseling patients before an elective proximal aortic replacement procedure, the predictive models based on data for >27,000 elective patients provide a guide to estimating the increased risk of perioperative death and major morbidity in the setting of renal disease, lung disease, heart failure, and other comorbidities.

The current STS ACSD study presents a first look at outcomes for repair of acute type A aortic dissection in North America, with 94% of the 9,289 emergent cases due to acute aortic dissection. Mortality in this cohort was 21.5%, which is very similar to the approximately 25% 30-day mortality for patients treated surgically in reports from the International Registry of Acute Aortic Dissection (12). The current cohort represents the largest report of emergent type A dissection repairs to date and, unfortunately, highlights that results with surgical treatment of this disease appear to have improved little over the past 20 years (13).

The most common indication for replacement of the ascending aorta and/or arch is thoracic aortic aneurysm (8,13). Current American College of Cardiology/American Heart Association/American Association for Thoracic Surgery/STS guidelines recommend evaluation for elective repair in asymptomatic patients with an ascending (Class I recommendation) or arch (Class IIa) diameter of 5.5 cm and prompt evaluation for surgical intervention in patients with symptomatic aneurysms (Class I) (14). These current joint U.S. society guideline size criteria recommendations are based on previous observations that the risk of a serious adverse event (rupture, dissection, death) exceeds the risk of elective operation when the maximum aortic diameter exceeds 5.5 to 6.0 cm. This recommendation is contingent upon the assumption that the risk of operation is approximately 5% (16). We show herein that the current elective operative mortality is actually only 3.5% across the U.S. and Canada, suggesting that current diameter thresholds may need to be reconsidered.

To this point, in a 2007 report from the International Registry of Acute Aortic Dissection, nearly 60% of acute type A dissection patients had ascending aortic diameters ≤5.5 cm at the time of dissection, and approximately 40%

**Table 4 Selected Predictors of Major Morbidity and Mortality Among All Patients**

| Variable | Adjusted OR (95% CI) | p Value |
|---|---|---|
| Status: emergent vs. elective | 6.72 (6.25–7.22) | <0.0001 |
| Pre-operative shock | 2.00 (1.71–2.34) | <0.0001 |
| Status: urgent vs. elective | 1.81 (1.69–1.93) | <0.0001 |
| Myocardial infarction within 6 h | 1.78 (1.26–2.51) | 0.0011 |
| Severe chronic lung disease | 1.72 (1.48–1.99) | <0.0001 |
| Any reoperation | 1.62 (1.48–1.78) | <0.0001 |
| Concomitant CABG | 1.59 (1.47–1.72) | <0.0001 |
| Chronic kidney disease stage 3 or greater, GFR <60 ml/min/1.73 $m^2$ | 1.55 (1.45–1.66) | <0.0001 |
| Concomitant mitral valve procedure | 1.54 (1.36–1.73) | <0.0001 |
| Arch involvement | 1.45 (1.31–1.62) | <0.0001 |
| Cerebrovascular disease | 1.37 (1.27–1.47) | <0.0001 |

Abbreviations as in Tables 1 and 3.

**Table 5 Selected Predictors of Operative Mortality Among Elective Patients**

| Variable | Adjusted OR (95% CI) | p Value |
|---|---|---|
| Pre-operative dialysis | 4.04 (2.56–6.37) | <0.0001 |
| Any reoperation | 2.29 (1.93–2.70) | <0.0001 |
| Concomitant CABG | 1.99 (1.70–2.32) | <0.0001 |
| Moderate or severe chronic lung disease | 1.85 (1.52–2.25) | <0.0001 |
| Congestive heart failure, NYHA class IV | 1.74 (1.28–2.38) | 0.0005 |
| Concomitant mitral valve procedure | 1.69 (1.34–2.14) | <0.0001 |
| Female vs. male | 1.57 (1.36–1.83) | <0.0001 |
| Immunosuppressive treatment | 1.55 (1.10–2.17) | <0.0113 |
| Age >70 yrs, 5-yr increments | 1.44 (1.33–1.56) | <0.0001 |
| Pre-operative atrial fibrillation | 1.32 (1.12–1.56) | 0.0011 |

NYHA = New York Heart Association; other abbreviations as in Tables 1 and 3.

**Table 6 Selected Predictors of Major Morbidity and Mortality for Elective Patients**

| Variable | Adjusted OR (95% CI) | p Value |
|---|---|---|
| Chronic kidney disease stage 4 or greater, GFR <30 ml/min/1.73 $m^2$ | 2.68 (2.18–3.30) | <0.0001 |
| Severe chronic lung disease | 2.05 (1.71–2.47) | <0.0001 |
| Any reoperation | 1.88 (1.71–2.07) | <0.0001 |
| Concomitant mitral valve procedure | 1.75 (1.52–2.01) | <0.0001 |
| Congestive heart failure, NYHA class IV | 1.57 (1.25–1.97) | <0.0001 |
| Concomitant CABG | 1.55 (1.44–1.67) | <0.0001 |
| Aortic arch aneurysm | 1.50 (1.31–1.72) | <0.0001 |
| Race: black vs. white | 1.50 (1.29–1.74) | <0.0001 |
| History of myocardial infarction | 1.32 (1.14–1.54) | <0.0001 |
| Age >70 yrs, 5-yr increments | 1.31 (1.24–1.39) | <0.0001 |

Abbreviations as in Tables 1, 3, and 5.

had diameters ≤5.0 cm (17). If we assume these dissections result in emergent operations, the mortality for those cases, on the basis of the present report, is 21.5%. With an overall elective mortality of only 3.5% for proximal aortic replacement (adjusted OR: 5.9 for operative mortality with emergent vs. elective cases), the question arises as to whether we are waiting too long to intervene. Given the large denominator of patients with ascending aortic diameters between 4 cm and 5 cm, however, it is likely not feasible to simply recommend lowering diameter thresholds as a means of improving overall outcomes by diminishing the number of urgent/emergent procedures (18). Rather, a more practical approach would be increased screening and improved medical therapy for patients at risk for aortic aneurysm and/or dissection (6). Continual broadening of clinical awareness of thoracic aneurysms and dissections and the methods of diagnosis should be expected to reduce the need for urgent or emergent operation and thereby reduce associated procedural morbidity and mortality.

**Study limitations.** The clinical registry studied was observational, and the results of the analyses represent hypothesis generation. Although the data source represents a significant majority of U.S. cardiac surgical centers and includes the most recent reported results, data were limited to those reported through the STS ACSD and did not reliably distinguish underlying aortic pathology necessitating proximal aortic replacement.

Further, details of the specific operative procedure performed, for example, proximal arch versus total arch, are limited in the data analyzed. However, given the only modest increase in operative and aortic cross-clamp times observed in cases in which concomitant arch replacement was performed (Table 1), we would predict that the majority of arch procedures reported herein represent proximal or hemiarch replacement. Data were also lacking regarding details of potentially important variations in aortic replacement technique including aortic diameter, connective tissue disorder diagnosis, degree of hypothermia, cerebral perfusion, and use of neurologic monitoring. Finally, all STS ACSD outcomes data are voluntarily self-reported without external adjudication of adverse events or universal auditing, which opens the possibility of under-reporting event rates.

## Conclusions

Proximal aortic replacement is increasingly being performed in North America. Current outcomes for ascending aorta and arch replacement are excellent for elective repair; however, results are much less favorable for patients requiring nonelective procedures. This finding suggests increased screening of at-risk populations as well as lowering aortic diameter thresholds triggering elective intervention could potentially improve outcomes by reducing the fraction of operative procedures performed in nonelective circumstances. The predictive models presented may serve clinicians in developing risk stratification strategies when they counsel patients.

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**Key Words:** aortic aneurysm and dissection ▪ aortic disease ▪ aortic surgery outcomes.