Aortic root surgery in the United States: A report from the Society of Thoracic Surgeons database

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Objective: The purpose of the present study was to evaluate the early clinical outcomes of aortic root surgery in the United States.

Methods: The Society of Thoracic Surgeons database was queried to identify all patients who had undergone aortic root replacement from 2004 to early 2010 (n = 13,743). The median age was 58 years (range, 18-96); 3961 were women (29%) and 12,059 were white (88%). The different procedures included placement of a mechanical valve conduit (n = 4718, 34%), stented pericardial (n = 879, 6.4%) or porcine (n = 478, 3.5%) bioprosthesis, stentless root (n = 4309, 31%), homograft (n = 498, 3.6%), and valve sparing root replacement (n = 1918, 14%).

Results: The median number of aortic root surgeries per site was 2, and only 5% of sites performed >16 aortic root surgeries annually. An increased trend to use biostented (porcine or pericardial) valves during the study period (7% in 2004 vs 14% in 2009). The operative (raw) mortality was greater among the patients with aortic stenosis (6.2%) who had undergone aortic root replacement, independent of age. Mortality was greater in patients who had undergone concomitant valve or coronary artery bypass grafting or valve surgery (21%). The lowest operative mortality was observed in patients who had undergone aortic valve sparing procedures (1.9%).

Conclusions: Most cardiac centers performed aortic root surgery in small volumes. The unadjusted operative mortality was greater for patients >80 years old and those with aortic stenosis, regardless of age. Valve sparing root surgery was associated with the lowest mortality. A trend was seen toward an increased use of stented tissue valves from 2004 to 2009. (J Thorac Cardiovasc Surg 2015;149:116-22)

Supplemental material is available online.

Aortic root replacement has historically associated with considerable morbidity and mortality.^{1,2} Recent technical advances in thoracic aortic surgery and improvements in cerebral and myocardial protection has improved outcomes³; however, significant morbidity and mortality has remained.⁴ The contemporary outcomes of aortic root surgery in the United States are uncertain. The purpose of

the present study was to better evaluate the early clinical outcomes and institutional characteristics of aortic root surgery in the United States.

METHODS

Patients

The patient population analyzed in the present study was obtained from the Society of Thoracic Surgeons (STS) Adult Cardiac Surgery Database (ACSD).⁵ The study included all patients aged ≥18 years who had undergone aortic root replacement from January 1, 2004 to early 2010 (n = 13,743). The data were collected using versions v2.52 (years 2004-2007) and v2.61 (years 2008-2010) of the STS database (available at: <http://www.sts.org/quality-research-patient-safety/national-database/database-managers/adult-cardiac-surgery-database/d>).

The exclusion criteria were active or treated endocarditis, type A aortic dissections, and an aortic aneurysm with locations other than the ascending aorta only or ascending aorta and aortic arch. When comparing the valve types used for aortic root reconstruction, only mechanical, stented (porcine or pericardial), stentless, and homograft valves were included; patients with autograft, ring, or band annuloplasty or who had missing or mismatched valve types were excluded. Patients with an unreported age were also excluded when comparing the operative outcomes by age. Previous reoperation was defined as any previous open heart procedure, such as previous coronary artery bypass grafting (CABG) and valve or other cardiac, great vessel, or congenital surgery. Univariate analysis was used to compare the surgical outcomes in the presence of preoperative conditions and concomitant procedures. When comparing the outcomes in the presence of aortic stenosis, increased age, concomitant CABG, concomitant valve, concomitant CABG and valve procedure, and

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Abbreviations and Acronyms

ACSD	= Adult Cardiac Surgery Database
CABG	= coronary artery bypass grafting
LOS	= length of stay
STS	= Society of Thoracic Surgeons

concomitant aortic aneurysm repair, any missing data in the area of interest were imputed as negative.

RESULTS

Patient and Operative Characteristics

The present study included 13,746 patients who had undergone aortic root surgery from 2004 to 2010 (Table 1). The patient ages in the study population ranged from 18 to 96 years (median, 58 years); 3961 were women (29%) and 12,059 were white (87%). A total of 1918 patients had undergone a valve sparing root procedure (15%) and 11,825 patients had undergone root reconstruction with a valve conduit. The prevalence of the various procedures was as follows: mechanical valve conduit, 37%; stented pericardial, 7% or porcine bioprosthesis, 4%; stentless root, 33%; and homograft, 4%. A total of 2724 patients had previously undergone cardiac surgery (21%). Concomitant procedures included CABG (n = 3811, 30%) and mitral and/or tricuspid valve surgery (n = 1201, 9%).

Morbidity and Mortality

The overall operative raw mortality of all patients undergoing aortic root surgery was 4.2%. The outcomes of patients with aortic stenosis, increased age, previous medial sternotomy, the use of select concomitant procedures, and various aortic root procedures are listed in Table 2. Operative mortality increased with patient age from 2.4% in patients <60 years old to 15% in patients >80 years old (Table 2). Aortic valve sparing root repair had the lowest incidence of operative mortality and in-hospital stroke. Concomitant procedures were associated with greater operative mortality, a longer length of stay (LOS), and increases in surgical complications, such as stroke, reoperation for bleeding, acute renal failure, and acute renal failure requiring dialysis (see Appendix Tables E2-E4). Operative mortality was greater among patients with aortic stenosis (6.2%) than in those without (3.5%) who had undergone aortic root replacement (Table 3). The incidence of acute renal failure, renal failure requiring dialysis, and LOS were increased in patients with aortic stenosis.

Operative mortality, LOS > 14 days, and total intensive care unit stay worsened significantly with increased patient age (Table 4). The operative mortality of patients ≥80 years was 15% and the rate of LOS > 14 days was 23% compared

with 2.3% and 6.1%, respectively, in patients <60 years. The proportion of female patients increased from 23% to 51% in patients <60 years old and those >80 years, respectively. In-hospital reoperations for any reason were more frequent in patients of increasing age.

Redo Sternotomy and Concomitant Procedures

Operative mortality and LOS > 14 days was greater in patients with previous sternotomy (8.9% and 15%) compared with those without (3.5% and 8.6%; Appendix Table E1). Concomitant procedures increased the operative mortality, rates of reoperation for bleeding, acute renal failure, and LOS > 14 days (Appendix Tables E2 and E3). The operative mortality of concomitant CABG, valve (mitral or tricuspid), and CABG and valve was 9.5%, 13%, and 21%, respectively (Table 3). The rate of acute renal failure and LOS > 14 days was 9.5% and 16% with concomitant CABG, 13% and 22% with concomitant valve surgery, and 17% and 30% for concomitant CABG and valve surgery, respectively.

Prosthesis Preference

Aortic valve sparing aortic root procedures resulted in an operative mortality of 1.9% (Table 1), which was less than that for mechanical valve conduit (3.8%), stented tissue valve conduit (5.6%), stentless root (5.8%), and homograft (7.6%) procedures (Table 5). The incidence of stroke was greatest in the homograft (4.0%) than in the mechanical valve conduit (2.0%), stented tissue valve (3.1%), stentless root (2.2%), and aortic valve sparing (2.3%) procedures. The rates of acute renal failure, reoperation for bleeding, hemodialysis, and LOS > 14 days were similar among the aortic root procedures. Mechanical (44%) and biostentless (40%) valves were the most frequently used, and biostented pericardial (8.1%), biostented porcine (4.4%), and homograft (4.4%) valves were less common.

Trends in Aortic Root Surgery

The percentage of patients undergoing aortic root surgery with mechanical, biostented, stentless, and homograft valves or valve sparing procedures were compared between 2004 and 2009 (Appendix Table E5). The mechanical and biostented valves were the most frequently used prosthesis from 2004 to 2009, with stentless and homograft valves less common after 2006. The usage of biostented valves has nearly doubled in 5 years. The proportion of valve sparing aortic root procedures has remained approximately 15%.

DISCUSSION

The present study included a large contemporary cohort evaluating aortic root replacement surgery trends in the United States reported to date with 13,746 patients included from 2004 to 2010. A recently published study by Williams and colleagues⁴ analyzed patients reported in the STS

TABLE 1. Patient population and outcomes stratified by aortic root procedure

Characteristic	Overall (n = 13,743)	Root reconstruction	
		Valve sparing (n = 1918)	Valve conduit (n = 11,825)
Age (y)	58 (48-69)	51 (39-63)	59 (49-69)
Female gender	28.82	27.48	29.04
Race			
White	87.75	86.08	88.02
Black	6.05	7.56	5.80
Asian	1.48	1.82	1.42
Hispanic	1.30	1.09	1.34
Demographic region			
Midwest	35.26	37.75	34.86
Northeast	16.88	15.85	17.05
South	28.80	24.50	29.50
West	19.06	21.90	18.60
BMI (kg/m ²)	28 (25-32)	27 (24-31)	28 (25-32)
Hypertension	66.34	59.65	67.53
Current or recent smoker	17.54	17.36	17.57
Hypercholesterolemia	48.89	41.24	50.13
Chronic lung disease	16.55	11.31	17.40
Renal function status			
GFR $\geq$ 90 mL/min/1.73 m ²	28.81	37.7	27.37
GFR 60-89 mL/min/1.73 m ²	52.25	51.25	52.41
GFR 30-59 mL/min/1.73 m ²	17.04	10.22	18.15
GFR $\leq$ 29 mL/min/1.73 m ²	0.97	0.31	1.07
Dialysis	0.92	0.52	0.99
Immunosuppressive treatment	2.13	1.67	2.21
Diabetes mellitus	13.03	8.17	13.83
Peripheral vascular disease	14.17	14.13	14.18
Cerebrovascular disease	9.18	7.40	9.47
History of myocardial infarction	8.61	5.26	9.16
History of congestive heart failure	25.85	12.51	28.02
Any previous cardiovascular surgery	19.82	13.45	20.85
Previous CABG	3.46	2.03	3.69
Previous valve procedure	12.46	6.62	13.40
Preoperative cardiogenic shock	0.27	0.21	0.28
Procedure status			
Elective	83.08	89.42	82.05
Urgent	16.92	10.58	17.95
Urgent reason			
Anatomy	29.11	46.80	27.41
Valve dysfunction	37.10	20.20	38.72
Congestive heart failure	22.66	15.76	23.32
Concomitant CABG	25.65	14.91	27.39
Concomitant mitral valve procedure	6.72	6.36	6.78
Concomitant arrhythmia correction	5.59	5.27	5.64
Operation time (h)	5.3 (4.3-6.8)	5.7 (4.5-7.1)	5.3 (4.2-6.7)
Crossclamp time (min)	139 (110-178)	157 (107-208)	138 (110-174)

Data presented as median (25th to 75th percentiles) or %. *BMI*, Body mass index; *GFR*, glomerular filtration rate; *CABG*, coronary artery bypass grafting.

ACSD from 2004 to 2009 who had undergone proximal aortic replacement, including combinations of aortic root ascending aorta with or without involvement of the aortic arch. Our study focused specifically on aortic root replacement and omitted repair of the ascending aorta and aortic arch. Multiple important findings were evident from our study.

Principal Findings

Aortic root repair remains an uncommon procedure for most surgical centers, with only a few sites reporting large annual case volumes. In the present study, the median number of aortic root surgeries per site was 2, and only 5% of institutions participating in the STS ACSD performed >16 aortic root surgeries in 2009 (Figure 1).

TABLE 2. Outcomes stratified by postoperative outcomes

Variable	Operative mortality	Stroke	Reoperation for bleeding	Acute renal failure	Hemodialysis	LOS > 14 d
Aortic stenosis	6.24	2.24	5.29	7.32	3.29	11.65
Age (y)						
<60	2.35	1.34	5.03	3.44	1.36	6.11
60-69	4.58	2.35	6.31	6.31	2.29	9.88
70-79	8.02	3.62	7.11	8.55	4.36	16.82
≥80	15.41	3.78	6.83	11.48	5.09	23.11
Concomitant procedures						
CABG	9.45	3.46	7.94	9.53	4.37	15.94
Valve (mitral or tricuspid)	13.29	2.77	8.80	13.00	5.26	22.47
CABG and valve	21.40	4.01	9.70	16.72	7.02	30.43
Aortic aneurysm	2.99	2.04	5.81	4.27	1.72	8.39
Redo sternotomy	8.92	2.64	7.20	8.52	4.00	14.68
Aortic root procedure						
Mechanical valve conduit	3.76	2.01	6.17	4.80	1.86	8.62
Stented tissue valve conduit	5.69	3.07	6.50	6.80	2.16	12.86
Stentless root	5.82	2.17	5.54	6.83	3.28	12.00
Homograft	7.63	4.03	6.36	6.14	3.18	10.17
Aortic valve sparing	1.88	2.26	6.00	5.80	2.40	10.45

Data presented as %. LOS, Length of stay; CABG, coronary artery bypass grafting.

Another finding of our study was an increasing trend during aortic root reconstruction to use biostented (porcine or pericardial) rather than mechanical, homograft, or biostentless valves (Figure 2). In 2009, 14% of patients received a biostented valve compared with only 7.6% received a biostented valve in 2004. The decision of

whether to implant a bioprosthesis or a mechanical valve has largely been dependent on the age of the patient and their preference toward 1 of 2 sets of complications: the requirement for chronic anticoagulation therapy and its complications in mechanical valves or structural valve deterioration with a bioprosthesis.⁶

TABLE 3. Outcomes stratified by aortic stenosis

Characteristic	Overall (n = 13,743)	Aortic stenosis	
		No (n = 8568)	Yes (n = 5175)
Age (y)	58 (48-69)	56 (45-67)	62 (52-72)
Female gender	28.82	23.90	36.97
BMI (kg/m ²)	28 (25-32)	28 (24-31)	28 (25-33)
Hypertension	66.43	66.29	66.65
Hypercholesterolemia	48.89	44.09	56.83
Chronic lung disease	16.55	15.51	18.28
Diabetes mellitus	13.03	9.18	19.40
Any previous cardiovascular surgery	19.82	19.40	20.52
Procedure status			
Elective	83.08	83.91	81.7
Urgent	16.92	16.09	18.3
Urgent reason			
Anatomy	29.11	36.48	18.37
Valve dysfunction	37.10	32.56	43.72
Congestive heart failure	22.66	20.09	26.40
Operation time (h)	5.3 (4.3-6.7)	5.4 (4.3-6.8)	5.2 (4.2-6.7)
Crossclamp time (min)	139 (110-178)	139 (109-179)	139 (111-176)
ICU stay (h)	45.8 (24.0-88.2)	45.0 (24.0-75.0)	47.5 (24.9-96.0)
LOS > 14 d	9.78	8.65	11.64
Septicemia in hospital	1.70	1.30	2.36
Cardiac arrest in hospital	3.38	2.80	4.33
Reoperation, any reason	10.88	10.62	11.30
Operative mortality	4.56	3.54	6.24

Data presented as median (25th to 75th percentiles) or %. BMI, Body mass index; ICU, intensive care unit; LOS, length of stay.

TABLE 4. Outcomes stratified by age group

Characteristic	Overall (n = 13,743)	Age (y)			
		<60 (n = 7262)	≥60 but <70 (n = 3361)	≥70 but <80 (n = 2432)	≥80 (n = 688)
Age (y)	58 (48-69)	49 (40-54)	64 (62-67)	74 (72-76)	82 (81-84)
Female gender	28.82	22.60	28.86	41.00	51.53
BMI (kg/m ²)	28 (25-32)	28 (25-32)	28 (25-32)	27 (24-31)	26 (23-29)
Hypertension	66.43	54.89	76.67	81.66	84.30
Hypercholesterolemia	48.89	37.69	59.51	63.90	62.21
Chronic lung disease	16.55	11.88	20.59	23.23	22.53
Diabetes mellitus	13.03	8.46	17.23	19.57	17.73
Any previous cardiovascular surgery	19.82	20.52	18.12	19.28	22.67
Procedure status					
Elective	83.08	85.27	81.82	80.47	75.29
Urgent	16.92	14.73	18.18	19.53	24.71
Urgent reason					
Anatomy	29.11	29.81	29.30	30.32	20.59
Valve dysfunction	37.10	39.07	35.68	35.79	33.53
Congestive heart failure	22.66	21.21	22.42	21.89	34.71
Operation time (h)	5.3 (4.3-6.7)	5.2 (4.2-6.6)	5.4 (4.3-6.8)	5.6 (4.4-7.0)	5.5 (4.3-7.0)
Crossclamp time (min)	139 (110-178)	138 (109-177)	140 (111-178)	143 (111-180)	138 (109-178)
ICU stay (h)	45.8 (24.0-88.2)	41.0 (23.0-69.0)	48.0 (25.2-93.0)	56.7 (29.0-120.0)	76.0 (44.0-167.0)
LOS > 14 d	9.78	6.11	9.88	16.82	23.11
Reoperation, any reason	10.88	8.88	11.72	13.94	17.01
Operative mortality	4.56	2.35	4.58	8.02	15.41

Data presented as median (25th to 75th percentiles) or %. *BMI*, Body mass index; *ICU*, intensive care unit; *LOS*, length of stay.

Two large randomized clinical trials, the Edinburgh Heart Valve Trial⁷ and the Department of Veterans Affairs trial,⁸ found no statistically significant differences between mechanical and bioprosthesis valves for systemic embolism,

valve thrombosis, and prosthetic endocarditis or survival. However, increased rates of bleeding were found in patients with mechanical valves, and bioprosthetic aortic valve replacement with structural valve deterioration was greater

TABLE 5. Outcomes stratified by valve type

Characteristic	Overall (n = 10,737)	Mechanical (n = 4683)	Biostented			
			Porcine (n = 468)	Pericardial (n = 867)	Biostentless (n = 4243)	Homograft (n = 472)
Age (y)	60 (49-60)	53 (44-60)	67 (58-76)	66 (57-74)	66 (57-74)	60 (48-70)
Female gender	29.48	21.27	35.47	29.41	37.59	32.20
BMI (kg/m ²)	28 (25-32)	28 (25-32)	27 (24-30)	28 (25-31)	28 (25-32)	27 (24-31)
Hypertension	68.08	63.32	72.44	72.32	72.28	65.47
Hypercholesterolemia	50.56	43.84	54.06	56.86	56.63	47.67
Chronic lung disease	17.59	15.43	19.66	17.76	20.08	14.41
Diabetes mellitus	13.90	9.83	18.80	16.96	17.66	11.02
Any previous cardiovascular surgery	20.80	21.76	20.09	16.26	19.49	31.99
Procedure status						
Elective	81.81	83.06	81.62	79.93	81.43	76.48
Urgent	18.19	16.94	18.38	20.07	18.57	23.52
Urgent reason						
Anatomy	26.83	32.87	20.93	26.44	23.35	13.51
Valve dysfunction	39.27	38.16	44.19	43.68	35.41	63.96
Congestive heart failure	23.45	18.89	25.58	20.69	29.44	16.22
Operation time (h)	5.3 (4.2-6.7)	5.2 (4.2-6.6)	5.2 (4.1-6.6)	5.3 (4.2-6.8)	5.4 (4.3-6.7)	5.3 (4.3-7.0)
Crossclamp time (min)	137 (110-174)	132 (106-168)	127 (97-169)	137 (104-173)	142 (115-178)	148 (115-188)
ICU stay (h)	46.5 (24.4-92.2)	46.0 (24.0-76.23)	57.9 (36.0-116.3)	48.5 (25.5-95.0)	47.0 (24.25-96.0)	44.4 (24.2-93.0)
LOS > 14 d	10.55	8.62	16.03	11.19	12.00	10.17
Reoperation, any reason	11.47	11.27	13.68	11.42	11.38	12.29
Operative mortality	4.98	3.76	7.48	4.73	5.82	7.63

Data presented as median (25th to 75th percentiles) or %. *BMI*, Body mass index; *ICU*, intensive care unit; *LOS*, length of stay.

FIGURE 1. Distribution of aortic root replacements by site (year 2009). IQR, Interquartile range.

in patients aged <65 years in the Veterans Affairs trial. Stentless bioprosthetic aortic valve replacement has been theorized to provide benefits in valve hemodynamics and clinical outcomes; however, these potential advantages compared with stented bioprosthetic valves could be offset by the increased technical complexity of implantation, with longer crossclamp and cardiopulmonary bypass times. The presence of calcification, which will increase the complexity and morbidity of redo aortic root replacement, could also be an issue. A recent meta-analysis of randomized controlled trials revealed that stentless valves do not increase perioperative risk; however, they did not exhibit benefits in hemodynamics or clinical outcomes compared with stented valves.⁹

Operative Mortality

Mortality was greater in patients >80 years old (15%) and those who had undergone concomitant valve or CABG and valve surgery (21%). These findings are consistent with the proximal aortic replacement predictors of operative mortality

reported by Williams and colleagues,⁴ who reported risk-adjusted odds ratios of 2.14 for concomitant CABG among all patients and 1.44 for patients aged >70 years undergoing elective procedures. In our study, all concomitant procedures increased operative mortality, including additive mitral or tricuspid valve repair, additive mitral or tricuspid valve repair with CABG, and CABG alone. Increased technical complexity, coupled with the substantially longer cardiopulmonary bypass and aortic crossclamp times, likely contributed to worse short-term outcomes.

The overall unadjusted operative mortality was greater in patients with aortic stenosis (6.2%) than in those without (3.5%) who had undergone aortic root replacement, regardless of age. Published data are sparse regarding the operative mortality of aortic root surgery in the presence of aortic stenosis. The pathophysiologic consequences of prolonged aortic stenosis, including myocardial hypertrophy and decreased left ventricular cardiac output, likely contribute to the greater operative mortality.

The lowest operative mortality was observed in patients who had undergone aortic valve sparing procedures (1.88%) compared with root reconstruction with a valve conduit (5.0%). Two types of aortic valve sparing root replacement have been common: aortic root remodeling, known as the Yacoub procedure,¹⁰ and the more commonly performed reimplantation of the aortic valve, known as the David procedure.¹¹ The low operative mortality reported in the present study is consistent with other recently published single-center studies. Kvitting and colleagues¹² reported an operative mortality of 0.9% in 233 patients undergoing David valve-sparing aortic root replacement at Stanford University from 1993 to 2009. Another study of 236 patients who had undergone a David procedure from 1997 to 2011 reported an operative mortality of 1.7%.¹³ The mortality of David procedures has been greater in high-risk situations. In a study of 110 patients with acute type A dissection, severe aortic insufficiency, or reoperation, the operative mortality was reported as 5.4% and 8.2% for the David and Bentall procedure patients, respectively.¹⁴

AORTIC ROOT SURGERY TRENDS

FIGURE 2. Trends in aortic root replacement prosthesis choice by year of surgery.

Study Limitations

Although the STS ACSD encompasses the significant majority of cardiac surgical centers in the United States and contains the most recent reported results, those cases performed at nonparticipating centers were not included in our analysis. The data regarding underlying aortic pathologic factors and variations in surgical technique, including connective tissue diagnosis, aortic diameter, and adjunct monitoring of cerebral perfusion, were not available for incorporation into the present study.

Clinical Implications

Most surgical centers in the United States performed ≤ 2 aortic root procedures in 2009, and only 5% of sites

performed >16 operations, making it more difficult to maintain the expertise required to maximize successful outcomes for these technically complex procedures. Studies have shown that an inverse association exists between hospital procedure volume and postoperative mortality for surgeries of the aortic root,^{6,7} and this is likely true for aortic root replacement, one of the most technically complex, yet least commonly performed, cardiac operations.

The lowest operative mortality was observed for patients who had undergone aortic valve sparing procedures, suggesting that the David procedure should continue to be the favored alternative, if technically feasible. Greater operative mortality was found among patients with aortic stenosis, patients >80 years old, and those who had undergone concomitant valve or CABG and valve surgery. Caution should be applied when considering aortic root replacement for patients with aortic stenosis without an aortic root aneurysm, because a less complex operation might be a safer alternative. Additional characterization of the STS ACSD aortic root surgery outcomes in these areas could assist in modifying the screening thresholds for elective repair, which should result in improved outcomes.

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APPENDIX TABLE E1. Outcomes by redo sternotomy

Characteristic	Overall (n = 13,743)	Redo sternotomy	
		No (n = 11,019)	Yes (n = 2724)
Age (y)	58 (48-69)	59 (48-69)	57 (45-68)
Female gender	28.82	28.97	28.23
BMI (kg/m ²)	28 (25-32)	28 (25-32)	28 (24-32)
Cerebrovascular disease	9.18	7.57	15.71
Diabetes mellitus	13.03	12.49	15.24
Congestive heart failure	25.85	23.42	35.68
Procedure status			
Elective	83.08	84.20	78.52
Urgent	16.92	15.80	21.48
Urgent reason			
Anatomy	29.11	32.40	19.32
Valve dysfunction	37.10	32.57	50.60
Congestive heart failure	22.66	22.11	24.27
Operation time (h)	5.3 (4.3-6.7)	5.1 (4.2-6.4)	6.5 (5.2-8.3)
Crossclamp time (min)	139 (110-178)	136 (108-174)	152 (118-194)
ICU stay (h)	45.8 (24.0-88.2)	45.0 (24.0-75.0)	50.0 (25.5-118.0)
LOS > 14 d	9.78	8.57	14.68
Pneumonia in hospital	4.29	3.76	6.46
Septicemia in hospital	1.70	1.47	2.61
Stroke in hospital > 72 h	2.11	1.98	2.64
Renal failure in hospital	5.45	4.69	8.52
Reoperation, any reason	10.88	9.77	15.35
Operative mortality	4.56	3.48	8.92

Data presented as median (25th to 75th percentiles) or %. *BMI*, Body mass index; *ICU*, intensive care unit; *LOS*, length of stay.

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APPENDIX TABLE E2. Outcomes by additive valve procedure (mitral and tricuspid)

Characteristics	Overall (n = 13,743)	Concomitant valve procedure (mitral and tricuspid)	
		No (n = 12,697)	Yes (n = 1046)
Age (y)	58 (48-69)	58 (48-68)	62 (52-73)
Female gender	28.82	27.79	41.40
BMI (kg/m ²)	28 (25-32)	28 (25-32)	27 (24-31)
Chronic lung disease	16.55	16.14	21.61
Diabetes mellitus	13.03	12.90	14.72
Any previous cardiovascular surgery	19.82	18.88	31.26
Congestive heart failure	25.85	23.59	53.35
Atrial fibrillation	11.40	9.96	28.87
Procedure status			
Elective	83.08	83.96	72.37
Urgent	16.92	16.04	27.63
Urgent reason			
Anatomy	29.11	31.12	14.88
Valve dysfunction	37.10	36.48	41.52
Congestive heart failure	22.66	20.62	37.02
Operation time (h)	5.3 (4.3-6.7)	5.2 (4.2-6.6)	6.5 (5.3-8.3)
Crossclamp time (min)	139 (110-178)	136 (108-173)	187 (149-234)
ICU stay (h)	45.8 (24.0-88.2)	45.0 (24.0-76.7)	72.0 (41.0-153.5)
LOS > 14 d	9.78	8.73	22.47
Pneumonia in hospital	4.29	4.00	7.84
Septicemia in hospital	1.70	1.58	3.15
Renal failure in hospital	5.45	4.83	13.00
Dialysis in hospital	2.31	2.06	5.26
Cardiac arrest in hospital	3.38	3.13	6.31
Reoperation, bleeding or tamponade	5.80	5.55	8.80
Reoperation, any reason	10.88	10.25	18.45
Operative mortality	4.56	3.84	13.29

Data presented as median (25th to 75th percentiles) or %. *BMI*, Body mass index; *ICU*, intensive care unit; *LOS*, length of stay.

APPENDIX TABLE E3. Outcomes stratified by additional CABG

Characteristic	Overall (n = 13,743)	Concomitant CABG	
		No (n = 10,214)	Yes (n = 3525)
Age (y)	58 (48-69)	55 (45-66)	66 (58-74)
Female gender	28.82	28.20	30.64
BMI (kg/m ²)	28 (25-32)	28 (25-32)	28 (25-32)
Hypertension	66.42	61.56	80.48
Current or recent smoker	17.54	16.61	20.23
Hypercholesterolemia	48.90	42.33	67.91
Stroke, history	6.61	5.65	9.39
Peripheral vascular disease	14.17	12.30	19.60
Diabetes mellitus	13.04	10.46	20.48
Any previous cardiovascular surgery	19.83	20.19	18.78
Congestive heart failure	25.85	24.20	30.61
Procedure status			
Elective	83.08	85.72	75.43
Urgent	16.92	14.28	24.57
Urgent reason			
Anatomy	29.12	27.48	31.87
Valve dysfunction	37.12	41.60	29.56
Congestive heart failure	22.62	24.88	18.82
Acute myocardial infarction	3.14	0.82	7.04
Operation time (h)	5.3 (4.2-6.8)	5.0 (4.1-6.4)	6.3 (5.1-7.9)
Crossclamp time (min)	139 (110-178)	133 (105-170)	160 (127-198)
ICU stay (h)	45.8 (24.0-88.2)	43.8 (23.9-72.0)	64.5 (30.0-121.0)
LOS > 14 d	9.78	7.66	15.94
Pneumonia in hospital	4.29	3.36	7.01
Septicemia in hospital	1.70	1.18	3.18
Renal failure in hospital	5.45	4.04	9.53
Dialysis in hospital	2.31	1.60	4.37
Cardiac arrest in hospital	3.38	2.43	6.13
Reoperation, bleeding or tamponade	5.80	5.06	7.94
Reoperation, any reason	10.88	9.09	16.09
Operative mortality	4.55	2.86	9.45

Data presented as median (25th to 75th percentiles) or %. CABG, Coronary artery bypass grafting; BMI, body mass index; ICU, intensive care unit; LOS, length of stay.

APPENDIX TABLE E4. Outcomes stratified by additional CABG and valve procedure (mitral and tricuspid)

Characteristic	Overall (n = 13,743)	Concomitant CABG and valve procedure (mitral and tricuspid)	
		No (n = 13,444)	Yes (n = 299)
Age (y)	58 (48-69)	58 (48-68)	69 (60-75)
Female gender	28.82	28.48	44.15
BMI (kg/m ²)	28 (25-32)	28 (25-32)	27 (24-32)
Hypertension	66.43	66.11	80.60
Hypercholesterolemia	48.89	48.43	69.57
Chronic lung disease	16.55	16.32	27.09
Dialysis for renal failure	0.92	0.86	3.68
Cerebrovascular disease	9.18	9.01	17.06
Diabetes mellitus	13.03	12.79	24.08
Any previous cardiovascular surgery	19.82	19.64	27.76
Congestive heart failure	25.85	25.17	56.52
Atrial fibrillation	11.40	11.04	27.76
Procedure status			
Elective	83.08	83.43	67.22
Urgent	16.92	16.57	32.78
Urgent reason			
Anatomy	29.11	29.67	16.33
Valve dysfunction	37.10	37.16	35.71
Congestive heart failure	22.66	22.13	34.69
Operation time (h)	5.3 (4.3-6.8)	5.3 (4.3-6.7)	7.4 (6.2-8.8)
Crossclamp time (min)	139 (110-178)	138 (109-176)	204 (162-253)
ICU stay (h)	45.8 (24.0-88.2)	45.4 (24.0-84.0)	105.0 (46.0-185.0)
LOS > 14 d	9.78	9.32	30.43
Pneumonia in hospital	4.29	4.20	8.70
Septicemia in hospital	1.70	1.62	5.02
Renal failure in hospital	5.45	5.20	16.72
Dialysis in hospital	2.31	2.20	7.02
Cardiac arrest in hospital	3.38	3.27	8.36
Stroke in hospital > 72 h	2.11	2.07	4.01
Reoperation, bleeding or tamponade	5.80	5.71	9.70
Reoperation, any reason	10.88	10.61	22.74
Operative mortality	4.56	4.18	21.40

Data presented as median (25th to 75th percentiles) or %. CABG, Coronary artery bypass grafting; BMI, body mass index; ICU, intensive care unit; LOS, length of stay.

APPENDIX TABLE E5. Biostented (porcine or pericardial) trends

Year	Overall	Mechanical	Biostented	Stentless	Homograft	Valve sparing
2004	686	37.8	7.6	35.4	9.0	10.2
2005	1916	37.3	7.2	38.0	4.6	12.9
2006	2252	33.9	8.3	38.3	4.2	15.3
2007	2337	37.4	9.8	33.0	2.3	17.5
2008	2399	39.6	13.5	28.3	3.3	15.3
2009	2488	37.4	13.8	30.5	3.1	15.3

Data presented as %.