Midterm follow-up of composite graft replacement of the aortic root (30-year experience)—remarkably safe, effective, and durable

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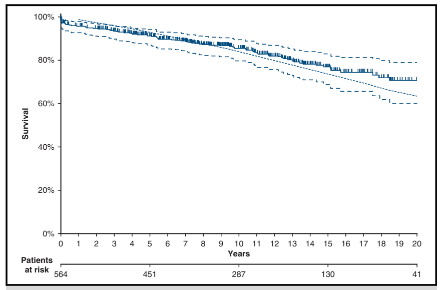
ABSTRACT

Objectives: Contemporary operative choices for aortic root disease include aortic root replacement (ARR) and a variety of valve-sparing and aortic root-repair procedures. We evaluate ultra-long-term outcomes of ARR, focusing on survival, freedom from late reoperation, and adverse events.

Methods: Prospectively kept records were used to accomplish long-term follow-up of patients who underwent ARR (4-pronged Yale survival assessment paradigm).

Results: Between 1990 and 2020, 564 patients underwent ARR (mean 56 years, 84% male). A modified Cabrol procedure (Dacron coronary graft) was employed in 9.0% (51/564) and concomitant coronary artery bypass grafting in 9.4% (53/564). There were 12.8% (72/564) urgent/emergent and 7.4% (42/564) redo procedures. Operative mortality occurred in 12 patients (2.1%) overall, or 1.4% (8/554) of nondissection and 1.3% (6/468) of elective first-time operations. Six of the 12 deaths presented with acute type A dissection, urgent operation, or reoperative states. Operative mortality dropped to 0.6% during the past 10 years. In total, 11 patients developed endocarditis. Stroke occurred in 11 of 564 patients (2.0%), 4 of whom had presented with type A dissection. Late events included bleeding in 2.8% (16/564), thromboembolism in 1.4% (8/564), and reoperation of the root in 5 of 564 (0.9%) at 15 years and more distal aortic segments in 16/564 (2.8%). Survival was no different from age/sex-matched controls.

Conclusions: This ultra-long-term experience finds ARR to be extraordinarily safe, effective, and durable, with minimal long-term bleeding, thromboembolism, or graft failure. This experience provides a standard of durability for ARR against which ultra-long-term outcomes with alternate procedures (valve-sparing, Ross, other) may be compared. (JTCVS Open 2024;17:1-13)



Long-term survival compared to age- and sex-matched population after composite-graft ARR.

CENTRAL MESSAGE

In a 30-year experience with replacement of the aortic root, stroke, bleeding, and root reoperation were minimal. Long-term survival was equivalent to an age- and sex-matched population.

PERSPECTIVE

Our overwhelming positive ultra-long-term experience with composite graft replacement of the aortic root provides a baseline against which outcomes with alternate procedures—including valve-sparing surgery, Ross operation, and PEARS procedure—can be compared.

In the past 3 decades, surgical techniques for aneurysms of the aortic root have expanded substantially, with the development of multiple alternative procedures in addition to traditional aortic root replacement.[1] For many years, the classic Bentall operation was the only available surgical solution for diseases involving the sinuses of Valsalva and the aortic valve. Bentall and De Bono[1] originally described their novel technique for complete replacement of the aortic valve and ascending aorta in a patient with free aortic regurgitation in 1968. They used a mechanical composite graft—consisting of a no. 13 Starr cage-ball valve attached to a crimped Teflon tube—accomplishing aortic root replacement with side-to-side reattachment of aortic wall carrying the 2 main coronary arteries. Nine years later, in 1977, Kouchoukos and colleagues[2] published a report on 25 patients with the important refinement of reattachment of fully mobilized coronary buttons. The Button–Bentall became

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Abbreviation and Acronym
CVG = composite valved graft

one of the most significant refinements of the classic procedure.

Later, in 1996, Bachet and colleagues[3] were the first to report an extensive experience of more than 200 patients, demonstrating the superiority of the Button–Bentall and its successful application for various etiologies. In the early 1990s, Galla and colleagues[4] introduced the BioBentall—a homemade composite graft manufactured intraoperatively using a stented biological valve inside a Dacron graft—enabling root replacement in patients deemed unable to take anticoagulants. The BioBentall provided excellent long-term survival and very low rates of thromboembolism, bleeding complications, and reoperation.[5]

Contemporary choices for the treatment of aortic root aneurysm include composite valve grafts (CVGs)[1] and a variety of valve-sparing aortic replacements, pioneered by David and Feindel[5] and by Sarsam and Yacoub,[6] as well as the long-standing Ross operation.

Over the previous years, many studies have reported the short- and midterm outcomes of patients who received CVG operations (Table E1). In a more recent paper, an increasing body of evidence suggested that the Ross procedure is associated with better long-term outcomes in young and middle-aged adults compared with conventional aortic root replacement.[7]

The objective of the present analysis is to report our ultra-long-term results with CVG in 564 patients operated by a single surgeon between 1990 and 2020, evaluating early and late survival, long-term freedom from reoperation, and long-term incidence of late adverse events (bleeding and thromboembolism).

Although CVG is more complex and technically challenging than separate aortic valve replacement and supracoronary grafting, it is vital to address the aortic root "head on" when that segment is dilated. We have recently recommended a general 5.0-cm size criterion for aortic replacement in good-risk patients, and this "left-shift" has been incorporated into the most recent "Guidelines."[8] Herein, we evaluate the contemporary safety of CVG.

METHODS

Patients

The Human Investigation Committee of Yale University approved this retrospective study #1609018416. The most recent annual reapproval was September 25, 2023, with the need for informed written consent waived.

Between January 1990 and 2020, 564 patients (474 male, 90 female) underwent CVG by a single surgeon (J.A.E.) at Yale University School of Medicine. Age range was 18 to 87 years, with a mean age of 55.7 ± 13.8 years (Table 1). Annuloaortic ectasia was the most common surgical indication in 535 (95.0%) patients, followed by type A aortic dissection in 33 (5.9%). Of the 564 patients, 53 had aortic stenosis, 415 had aortic insufficiency, and 21 had both. These proportions were stable during the study. Marfan syndrome was present in 42 patients (7.4%) and bicuspid aortic valve in 166 (29.4%). In total, 101 (17.9%) had a history of coronary artery disease.

The yearly number of patients operated increased progressively over the decades of this experience (Figure E1). This increase in patients treated in the more recent portion of the experience arithmetically decreased the mean duration of follow-up.

Surgical Techniques

Surgical techniques were as follows[9]: The femoral artery was used routinely for arterial cannulation (507/564, 90.0%) unless the descending aorta was atherosclerotic (on routine computed tomography scan or intraoperative transesophageal echocardiogram), in which case an alternate site was used (13/564 axillary [2.3%], 48/564 aortic arch [8.5%]).[10,11] In this experience, we strongly favored femoral cannulation. Our previous studies were very supportive of the safety and utility of this approach.[10,11] Also, this allows easy open distal anastomosis, an option that we often pursue. Axillary cannulations were done by direct insertion and not with a side-arm graft.[12] In the vast majority of patients, a modified Bentall–De Bono method was used, with button reimplantation of the coronary arteries into the neoaorta.[13] A modified Cabrol procedure (Dacron coronary graft) was done in 9.0% (51/564), of which 9 (1.6%) were redo and 8 (1.4%) were urgent/emergent procedures. Concomitant coronary artery bypass grafting was performed in 9.4% (53/564) of cases. Mean crossclamp and cardiopulmonary bypass times were 117.9 ± 23.4 minutes (range, 20-179 minutes) and 160 ± 31.8 minutes (range, 21-353 minutes), respectively. Deep hypothermic circulatory arrest was used for partial or total aortic arch replacement in 32.6% (184/564), with a mean duration of 26.9 minutes (range, 14-48 minutes). We started early in our experience with straight deep hypothermic circulatory arrest for brain protection. We studied clinical and neurologic outcomes in detailed multiple neuropsychometric studies.[14-17] These were so favorable that we never adopted antegrade or retrograde perfusion.

As the size at the aortic annulus determines the size of the composite graft, we generally beveled the graft to accomplish the distal anastomosis

TABLE 1. Patient characteristics

Patient characteristics	Total patients = 564
Age, y, mean ± SD	55.57 ± 13.76
Height, cm, mean ± SD	177.8 ± 10.8
Weight, kg, mean ± SD	88.4 ± 18.3
BMI, mean ± SD	27.9 ± 5.2
Male sex	474 (84%)
Hypertension	376 (66.6%)
COPD	81 (14.3%)
Diabetes mellitus	44 (7.8%)
Chronic renal insufficiency	25 (4.4%)
Dyslipidemia	199 (35.2%)
Coronary artery disease	103 (18.2%)
Ever smoker	176 (31.2%)
Bicuspid aortic valve	166 (29.4%)
Positive family history of aneurysm disease	131 (23.2%)

SD, Standard deviation; *BMI*, body mass index; *COPD*, chronic obstructive pulmonary disease.

TABLE 2. Early (30-day) readmission

Postoperative complications	Number of incidences (N)	Percentage of readmission (%)
Rapid atrial fibrillation/arrhythmia	21	28.7
Pericardial effusion	12	16.4
Infection (sternal, groin, saphenous vein site)	9	12.3
Altered mental status/syncope/ visual changes	8	10.9
Dyspnea	4	5.4
Pain	3	4.1
Stroke/TIA/TE	3	4.1
Unknown	2	2.7
Hypotension	1	1.3
Fever	2	2.7
Pleural effusion	1	1.3
Pneumonia	1	1.3

Total = 73 patients. Please note the total number of incidences is greater than the total number of patients readmitted due to the fact that a few patients had multiple complications on readmission. *TIA*, Transient ischemic attack; *TE*, thromboembolic event.

to the upper aorta or to an aortic arch graft, if that had been necessary and constructed earlier in the operation.[18]

In addition to the cases reported in this series, we performed 22 V-shaped noncoronary sinus remodeling procedures. These are not included in the present series.

We had such good results with straight tube grafts that we used very few Valsalva Dacron grafts. We do believe that the Valsalva grafts provide a superb option which, among other advantages, facilitates the coronary button attachments. The Valsalva grafts, we believe, came later to market in the United States than elsewhere, and most of the experience we are reporting had already been accumulated.

In terms of surgical details, the proximal anastomosis of the valved conduit to the aortic annulus was done with interrupted, everting, pledgeted mattress sutures of 4-Ti-Cron without felt reinforcement of the graft-to-annulus anastomosis. The coronary button anastomoses were done with running 4-0 PROLENE (Ethicon), incorporating a Teflon "washer." The distal aortic anastomosis was done with running 3-0 PROLENE with an external Teflon strip and several interrupted pledgeted sutures of 4-0 Ti-Cron placed internally to reinforce the posterior wall.[19] When Dacron graft-to-graft anastomoses were required, these were done with running 4-0 PROLENE. Cold crystalloid cardioplegia was used, administered antegrade and retrograde, unless there was significant aortic insufficiency, in which case only retrograde cardioplegia was given. Straight deep hypothermic arrest, without cerebral perfusion, was used in all circulatory arrest cases. BioGlue was not used on the proximal annular anastomosis or on the coronary button anastomoses, but occasionally on the distal aortic anastomosis or on the Dacron graft-to-graft anastomosis.

Mechanical and tissue prostheses were used in 427 (75.7%) and 136 (24.2%) patients, respectively. The decision to use a mechanical or tissue valve was made according to the patient's age, comorbidities, and personal preferences. In general, tissue valves were used in older patients or those with a shorter life expectancy, as well as in those who were unwilling to accept anticoagulation.

Postoperative Management and Clinical Follow-up

All patients with a mechanical valve received oral warfarin postoperatively. Long-term anticoagulation was maintained with a target international normalized ratio of 2 to 2.5 for St Jude valves and 1.8 to 2.5 for On-X valves. Eighteen patients in the PROACT Xa On-X valve study received one baby aspirin daily in addition to their coumadin. No anticoagulation was used for the biologic conduits in the early or late perioperative periods unless indicated for other reasons, such as atrial fibrillation. For patients with a biological conduit, we did not use aspirin or other anticoagulant agents unless there was a separate indication outside of the aortic root replacement.

Long-term survival information was determined based on our 4-pronged approach,[20] including clinical follow-up, Social Security Death Index, EPIC death information, and online obituary check. In addition, a completed imaging study signified survival to that point. Survival follow-up was 100% complete. No patient was counted as alive beyond the last definite report or contact. For follow-up of complications, record review and telephone interview with patients or close relatives were used to determine the long-term incidence of late reoperation, bleeding, stroke, and thromboembolism. The cause of death was available for 52 of 96 mortalities (56.5%). These data revealed the following major death categories: cancer, sudden death, cardiac failure, neurologic event, infection, hemorrhage, accident, old age, and miscellaneous causes.[21]

Late adverse events were defined according to the 2008 version of the Guidelines for Reporting Mortality and Morbidity After Cardiac Valve Intervention.[22] Stroke was defined as a prolonged (>72 hours) or permanent neurologic deficit that was associated with abnormal results of magnetic resonance imaging or computed tomographic scans. A transient ischemic attack was characterized by fully reversible symptoms of short duration (without radiographic evidence of any lesion). A bleeding event was defined as an episode of major internal or external bleeding that caused death, hospitalization, or permanent injury, or necessitated transfusion.

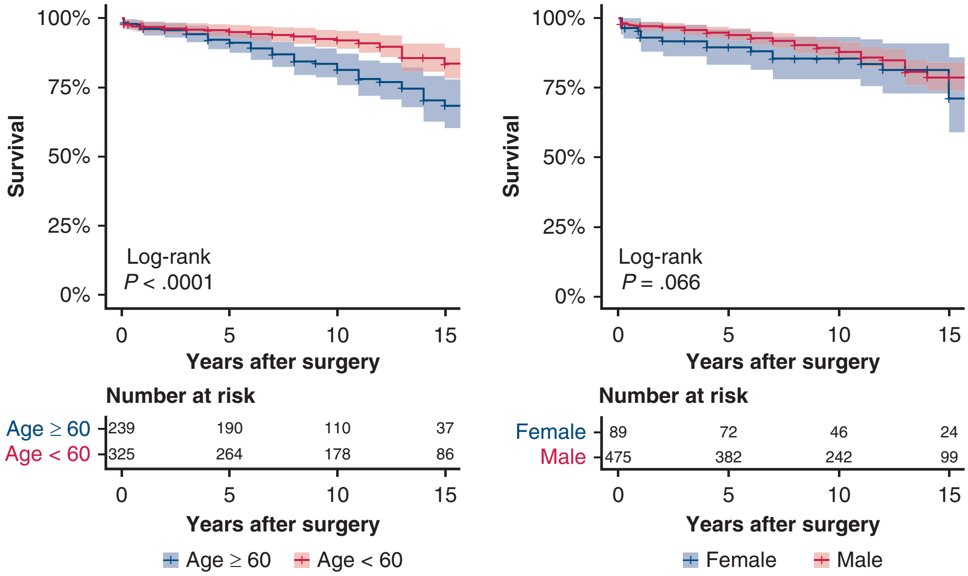
Statistical Analysis

All statistical analyses were performed with R software, version 4.1.2 (R Foundation for Statistical Computing) and SPSS, version 17.0 (SPSS Inc). Differences between groups were compared with the Wilcoxon rank sum test or the Fisher exact test, as appropriate. Survival rates were estimated using the Kaplan–Meier method and compared with the log-rank test. All tests are 2- tailed. Cumulative incidences of aortic reoperation, bleeding, and thromboembolism were modeled with death as a competing risk event.

Follow-up time for survival refers to the duration between the date of the operation and the date of death. The realized survival in the overall CVG patient group was compared with the expected survival for a normal age- and sex-matched population in the United States.[23] The general population age- and sex-specific death rates were obtained from the Centers for Disease Control and Prevention National Vital Statistics Reports (http://www.cdc.gov/nchs/products/nvsr.htm), for the median year 2010.

RESULTS

The mean age of patients was 55.6 years overall and 52.2 ± 13.8 (range 14-86) and 65.7 ± 10.2 (18-87) years in the mechanical and tissue valve groups, respectively. The older age of the patients with tissue valves was statistically significant ($P < .0001$). Of the 427 patients who received a mechanical valve conduit, 357 were male (83.6%) and 70 were female (16.4%). A prefabricated St Jude valved conduit (St Jude Medical) (or more recently, an On-X valved conduit) was selected for these patients. Among the 136 patients who received a biologic conduit, there were 117 male (86.0%) and 19 female (14.0%) patients. A Carpentier-Edwards or Edwards Magna or Magna Ease tissue valve (Edwards Lifesciences) was hand-sewn into a Hemashield graft (Boston Scientific)



Interval (years)	Survival (%)	
	Age < 60	Age ≥ 60
1	96.9	96.2
5	95.2	91.2
10	92.1	81.4
15	83.6	68.5

Interval (years)	Survival (%)	
	Male	Female
1	97.3	93.1
5	94.2	89.5
10	88	85.6
15	78.8	71.3

A B

FIGURE 1. Kaplan–Meier survival in patients with composite graft replacement according to age and sex. A, Predictably, patients younger than 60 years of age have a markedly better long-term survival than patients aged 60 and older, likely reflecting extra-aortic comorbidities. B, There was no significant difference in survival according to sex. 95% confidence intervals are depicted via *shading*.

to create the biologic conduit before cardiopulmonary bypass was initiated. In recent years, a Medtronic Freestyle Aortic Root Bioprosthesis (Medtronic) was used as a biological option as well. One patient underwent homograft root replacement. The mean duration of follow-up was 6 years, as the number of procedures done yearly increased with time (Figure E1).

Operative Mortality and Morbidity

Operative deaths occurred in 12 patients (2.1%), 8 after mechanical composite and 4 after tissue valve conduit implantation. Four of the 12 early deaths (33.3%) occurred in patients with acute type A dissection. Mortality in patients with acute type A dissection who needed aortic root replacement was 18.4% (17/92). Eight of the 12 deaths presented with either acute type A dissection, urgent operation, reoperative states, ejection fraction <30%, or age >80 years. Although the operative mortality was 2.0% in the whole series, it dropped to 0.6% during the past 10 years.

Perioperative stroke occurred in 2.0% (11/564) of patients. Ten of these 11 patients with stroke had mechanical prostheses, and one had a previous history of stroke. One patient had a biological prosthesis, and a previous history of stroke. Reexploration for bleeding occurred in 4.6% (26/564), of whom had 18 mechanical prostheses and 8 had biological prostheses. Thirty-day readmission rate was 13.2% (73/552) in 576 hospital survivors. The operative complications leading to 30-day readmission are listed in Table 2.

Long-Term Follow-up

By the end of the short- and long-term follow-up, 92 patients had died, including 71 in the mechanical prosthesis group and 21 in the tissue valve group. We were able to ascertain the cause of death in 52.0% (50/92) of total deaths recorded, via chart review and using the Social Security Death Index. Late deaths were attributed to various causes. According to Blackstone and Kirklin[22]'s nosology originally used for reporting results after valve surgery, the cause of deaths was broadly classified into the following categories: cancer, sudden death at home, cardiac failure, neurologic causes, infection, hemorrhage, and other miscellaneous causes. The cause of death in the remaining patients was undetermined.

Long-term survival for the entire group was 91.3%, 85.4%, 76.9%, and 70.6% at 5, 10, 15, and 20 years. Long-term survival for patients aged less than 60 years was 96.9%, 95.2%, 92.1%, and 83.6% at 1, 5, 10, and

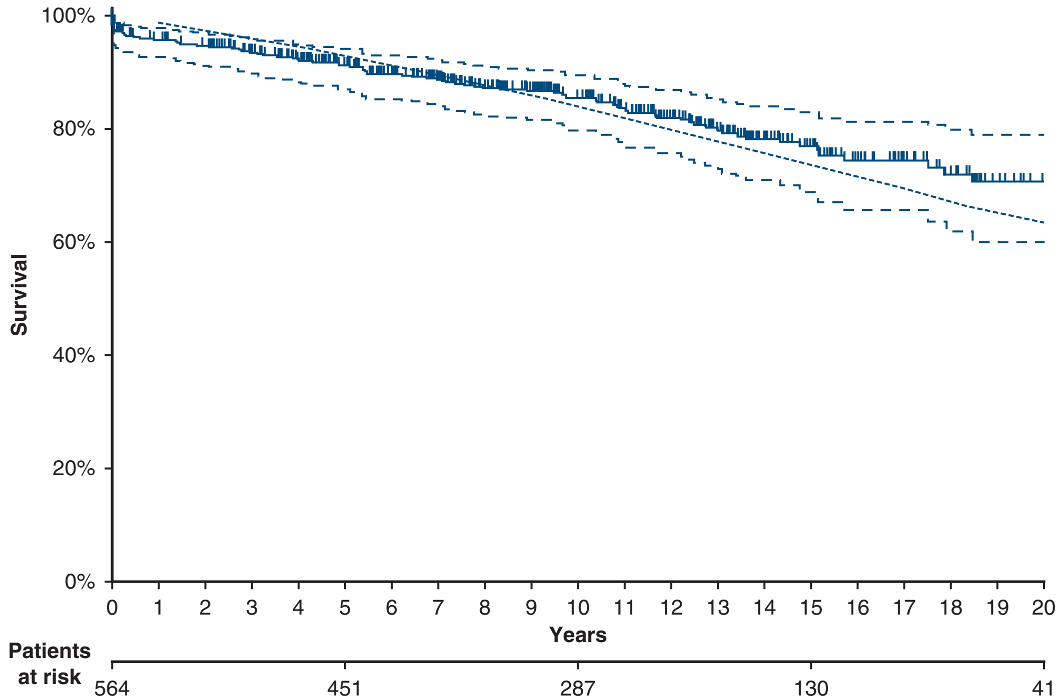
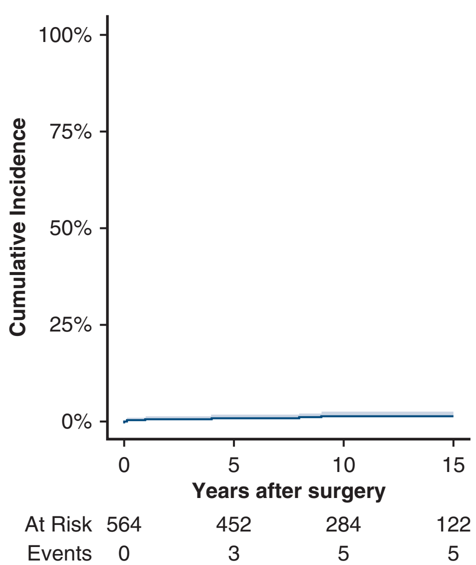
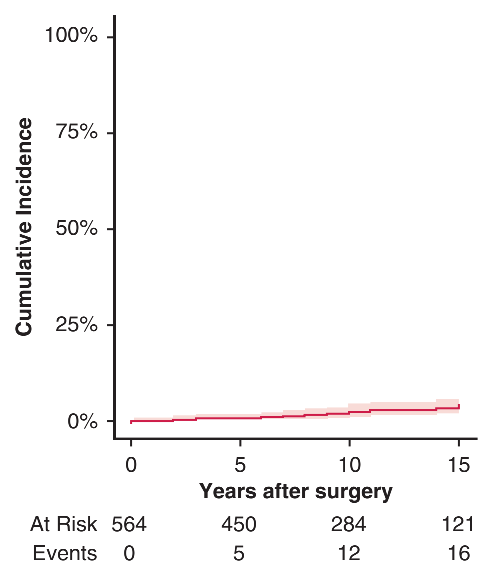


FIGURE 2. Long-term survival compared with age- and sex-matched general population of patients after composite graft aortic root replacement. Not only is the composite graft survival not inferior to that of the control population, but at 20 years, it is significantly better than the control population ($P = .044$, log-rank test) Please note the restoration of the aneurysm patients to a normal survival. (*Thick dashed line* indicates age- and sex-matched cohort, *thin dashed line* indicates 95% confidence interval, and *solid line* indicates patient cohort).



Interval (years)	Number at risk	Estimate	Standard error	95% CI
5	452	0.006	0.003	0.002, 0.015
10	284	0.011	0.005	0.004, 0.025
15	119	0.011	0.005	0.004, 0.025

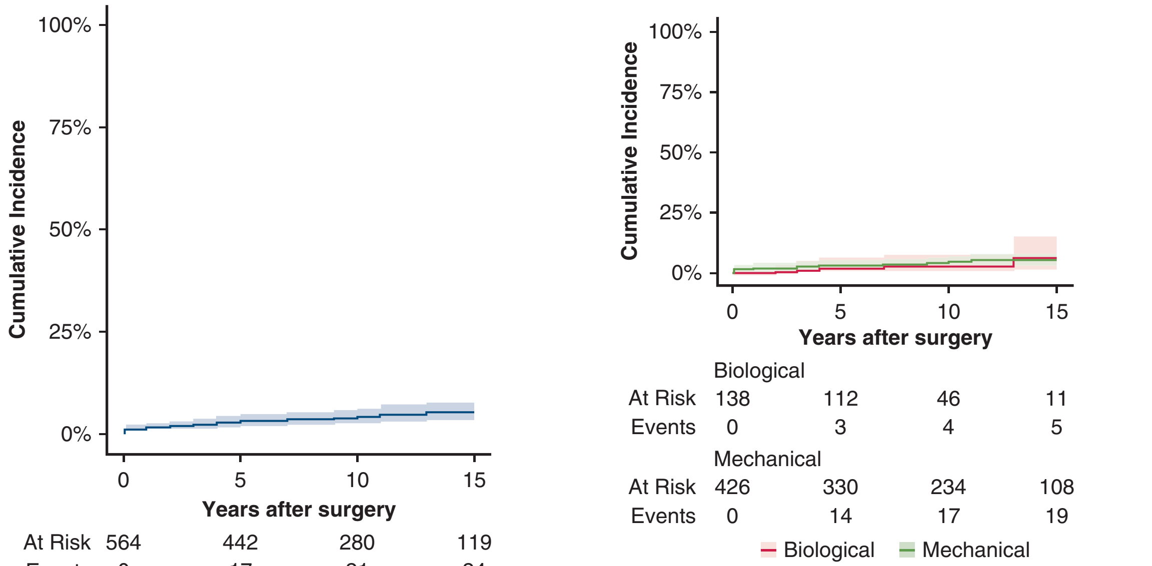
A



Interval (years)	Number at risk	Estimate	Standard error	95% CI
5	450	0.009	0.004	0.004, 0.020
10	284	0.028	0.008	0.015, 0.047
15	121	0.049	0.013	0.027, 0.080

B

FIGURE 3. A, Cumulative incidence of reoperation on the aortic root with death as a competing risk event. At 15 years, the incidence of aortic root reoperation is 1.1%. B, Cumulative incidence of reoperation on other segments with death as a competing risk event. At 15 years, the incidence of reoperation on other segments of the aorta is 4.9%. 95% confidence intervals are tabulated in the figure.



Interval (years)	Number at risk	Estimate	Standard error	95% CI
5	442	0.031	0.008	0.019, 0.049
10	280	0.042	0.009	0.027, 0.063
15	119	0.053	0.011	0.034, 0.078

A

Valve	Interval (years)	Number at risk	Estimate	Standard error	95% CI
Biological	5	112	0.023	0.013	0.006, 0.060
Biological	10	46	0.032	0.016	0.010, 0.076
Biological	15	11	0.061	0.033	0.017, 0.147
Mechanical	5	330	0.034	0.009	0.020, 0.055
Mechanical	10	234	0.045	0.011	0.027, 0.069
Mechanical	15	108	0.053	0.012	0.033, 0.080

B

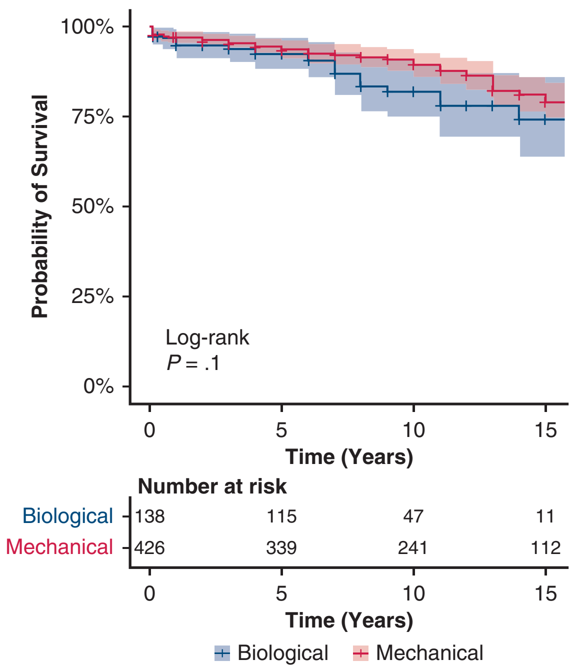
FIGURE 4. A, Cumulative incidence of bleeding and thromboembolism on the overall population with death as a competing risk event. At 15 years, freedom from bleeding and thromboembolism is 95%. B, Cumulative incidence of bleeding and thromboembolism according to valve prothesis with death as a competing risk event. At 15 years, freedom from bleeding and thromboembolism is 95% for mechanical and 94% for biological. 95% confidence intervals are tabulated in the figure.

15 years versus 96.2%, 91.2%, 81.4%, and 68.5% in patients older than 60 years (Figure 1) ($P \leq .001$). Long-term survival for patients with composite graft aortic root-replacement surgery was not statistically different between male and female patients and was comparable with the general population (Figures 1, *B*, and 2). Major late adverse events included bleeding in 2.9% (16/564) and thromboembolism in 1.4% (8/564) patients.

There were 5 reoperations on the aortic root. Those second procedures included the following: one coronary artery bypass graft (right internal mammary artery to right coronary artery) for coronary button osteal narrowing and 4 reoperations for endocarditis (2 mechanical and 2 biologic valves). The cumulative incidence of reoperation on the aortic root was 0.6%, 1.1%, and 1.1% at 5, 10, and 15 years, respectively (Figure 3, *A*). The cumulative incidence of reoperation in other (distal) aortic segments was 0.9%, 2.8%, and 4.9% at 5, 10, and 15 years, respectively (Figure 3, *B*). The cumulative incidence of major late events (bleeding, thromboembolism) was 3.1%, 4.2%, and 5.3%, at 5, 10, and 15 years, respectively (Figure 4, *A*).

Long-term survival was not significantly different between patients receiving mechanical valves (97.2%, 93.8%, 89.4%, and 79.1% at 1, 5, 10, and 15 years, respectively) and bioprosthetic valves (94.8%, 92.5%, 82.1%, and 74.2%, at 1, 5, 10, and 15 years, respectively) (log-rank $P = .1$) (Figure 5). Cumulative incidence rates of bleeding and thromboembolic events were also not significantly different between the 2 groups (Figure 4, *B*).

Long-term biological valve complications: Endocarditis. Nine patients developed endocarditis of the original biological aortic valve. Two required open reoperation. All are currently alive after medical or surgical treatment.



Interval (years)	Survival (%)	
	Mechanical	Biological
1	97.2	94.8
5	93.8	92.5
10	89.4	82.1
15	79.1	74.2

FIGURE 5. Kaplan–Meier survival according to valve prosthesis type. There was no significant difference in survival. 95% confidence intervals are depicted via *shading*.

Structural valve deterioration. Six patients required transcatheter aortic valve replacement for aortic stenosis (n = 2) or aortic insufficiency (n = 4) of the biological valve—at 10, 13, 14, 15-, 15, and 18 years' postoperatively.
Late atrial fibrillation requiring anticoagulation. Ten patients developed new atrial fibrillation during the follow-up interval, requiring coumadin treatment.

DISCUSSION

Early Mortality

The operative mortality in our series was 2.0% in the whole series and dropped to 0.6% during the past 10 years, which compares favorably with earlier and recent series, such as those reported in our previous update by Mok and colleagues[24] (3.1%), as well as Kalkat and colleagues[25] (10.7%), Kirali and colleagues[26] (8.3%), Sioris and colleagues[27] (4%), Michielon and colleagues[28] (5.2%), Pacini and colleagues[29] (6.9%), Svensson and colleagues[30] (1%), Di Marco and colleagues[31] (5.3%), and Woldenkrop and colleagues (5.7%).[32] The "button" technique was used in most of these studies, with the exception of Pacini and colleagues,[29] in which the classic Bentall technique was used in one-third of their patients (34.3%, 94/274) between 1978 and 2001. Kirali and colleagues[26] found severe bleeding, low cardiac output syndrome, acute respiratory distress, and cerebrovascular event as the causes of hospital mortality. Others showed advanced age (>70 years), concomitant coronary artery surgery, impaired left ventricular function, urgent or emergency cases, prosthetic valve size ≤23 mm, reoperation, congestive heart failure (New York Heart Association classes II, IV), and hospital activity volume ≤8 procedures/year as risk factors for 30-day mortality.

Late Survival

Our overall survival was 91.3%, 85.4%, 76.9%, and 70.6% at 5, 10, 15, and 20 years, respectively. These survival numbers equal or exceed those of most other reports. Our results provide ultra-long follow-up, rarely available for such long durations.[10-13,19-22]

It is important to point out that, remarkably, survival was not significantly different from age- and sex-matched controls. This statistic connotes real-world restoration to good health by the procedure invented years ago by Bentall and DeBono. Interestingly, Etz and associates[33] had reported similar survival matches with the general population in men but not in women. In that study, the mortality of women was twice as high as the age-matched female population. We saw only a trend toward decreased long-term survival in women compared to men.

Freedom From Late Events

Our incidence of reoperation on the aortic root (1.1% at 10 years) compares favorably with other reports (Figure 3). Our report carries follow-up out to longer time periods than most earlier reports, again substantiating the great patient benefit from composite graft replacement, essentially negating the virulent death of ascending aortic aneurysm disease. Our rates of thromboembolism and hemorrhage were lower than expected with mechanical aortic valve replacement. We suspect that the valve may be "washed" very well by flowing blood, as it is the same exact diameter as the graft. Also, our patients with aortic root disease are usually free of atherosclerosis[34] and have good left ventricular ejection fraction.

Benchmark for Comparison With Alternate Techniques

Our 30-year observation period marks our study as among the longest duration late follow-up studies of the

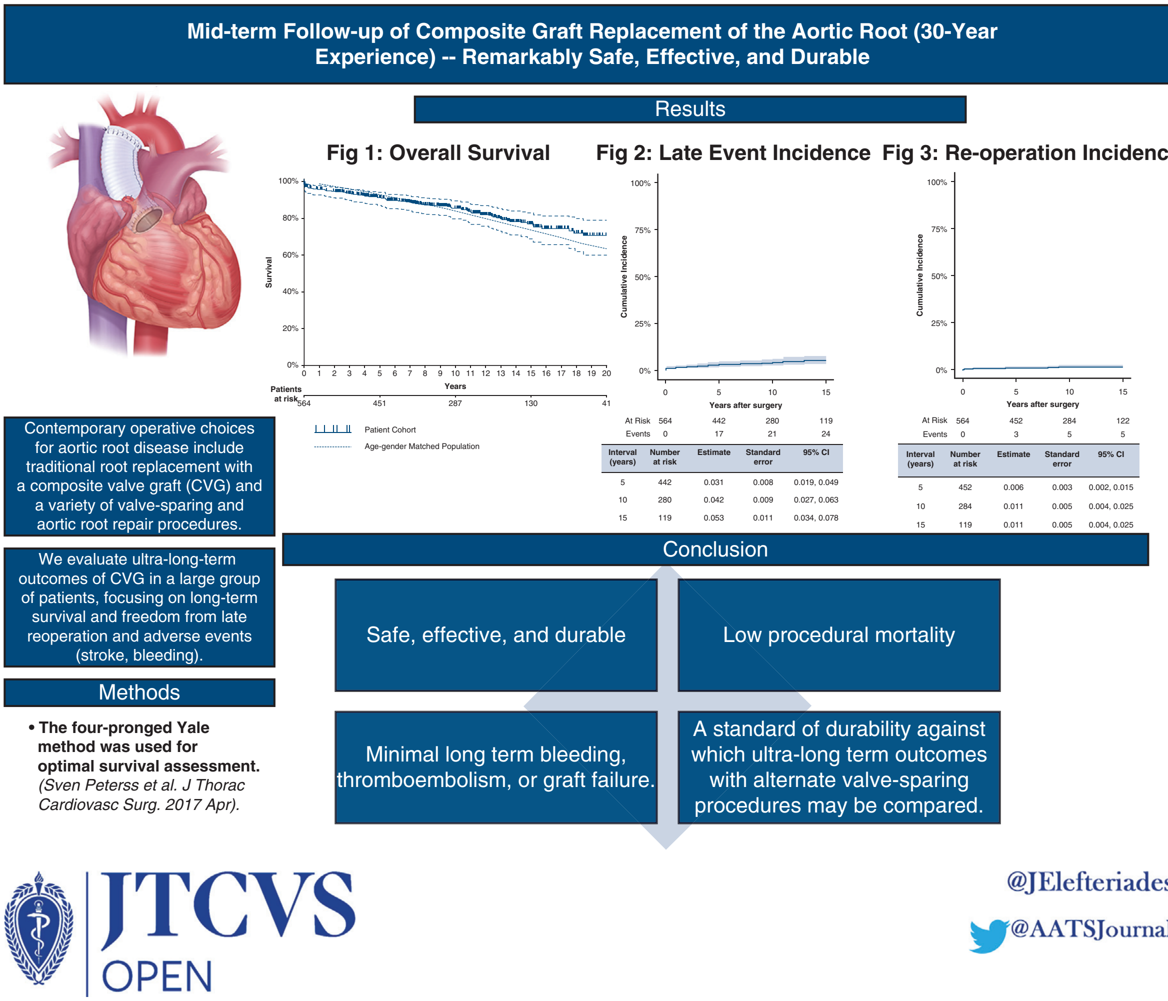


FIGURE 6. Our 30-year experience with replacement of the aortic root. Long-term survival was equivalent to an age- and sex-matched population.

Bentall procedure. In our clinical program, we have taken a very conservative stance with regards to Ross procedures, homografts, and valve-sparing procedures, favoring the known durability of mechanical and biological composite graft replacement. Aortic root replacement can be carried out with excellent outcomes and low mortality when performed at specialized centers.[35] The data provided in the present study regarding short- and long-term outcomes after traditional mechanical and biological aortic root replacement can serve as a benchmark for the evaluation of the advantages and disadvantages of various alternative valve-sparing procedures for various aortic root pathologies (valve-sparing root replacement, Ross procedure, personalized external aortic root support [ie, PEARS] operation, etc) as long-term outcomes with these alternative techniques continue to evolve with time. Specifically, the data in this study can serve as a benchmark vis-à-vis the aortic root alternative procedures of valve-sparing surgery, Ross procedure, and the PEARS operation.

Limitations

This retrospective study has several limitations. This is a single-surgeon experience at a high-volume center, and the results may not be generalizable. The recently released Guidelines document defines a "high volume center" as one that performs at least 30 to 40 aortic procedures annually; the Guidelines also recommend experienced surgeons and a multidisciplinary aortic team.[8] Although the scope of these cases covers a 30-year period, these operations became more and more numerous in the latter part of the experience, leading to a mean duration of follow-up of 6 years. There were only 6 cases of perioperative endocarditis (1.3%) and only 7% of patients had Marfan disease—two entities that are capable of diminishing early- and long-term outcomes. Patient follow-up was retrospective for some patients. However, we made calculations only up to the point of last confirmed contact. Brief or minor neurologic or hemorrhagic events may have been forgotten by patients by the time of interview. The precise cause of total deaths was identified in only 52.0% of patients who died, despite diligent search of the records. This is a single-center, single-surgeon experience, and results may not be generalizable. This study did not include any formal quality-of-life assessments, although we have done these on a large subset in the past.[E1]

CONCLUSIONS

We conclude that composite graft replacement of the aortic root is associated with low operative risk and produces excellent long-term survival, low incidence of late reoperation or late aortic events, and vanishingly low incidence of reoperation in the root portion of the aorta, although there remains the obligatory occasional need for additional operations on more distal aortic segments (see Figure 6 for a graphical abstract of the study). Those subsequent distal operations merely represent natural progression of aortic disease.

Conflict of Interest Statement

Dr Elefteriades is a Principal of CoolSpine. All other 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: composite aortic graft, Cabrol procedure, aortic root repair, valve sparing, Dacron coronary graft, aortic root replacement

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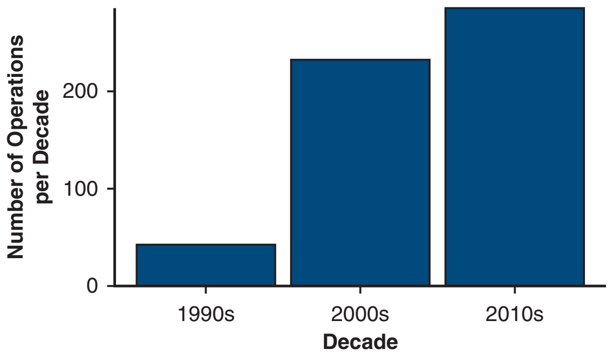

FIGURE E1. Surgical cases per decade.

TABLE E1. Reports on long-term outcomes of composite graft root replacement

First author	Time period	Survival
Etz et al[33]	1987-2005	93% (5 y) 89% (10 y)
Etz et al[E2]	1993-2005	4.8/100 patient y
Guilmet et al[E3]	1980-2000	85% (10 y) 60% (20 y)
Bachet et al[3]	1973-1994	89% (1 y) 77.9% (5 y) 67.7% (12 y) 61.3% (12 y)
Kouchoukos et al[13]	1974-1990	61% (7 y) 48% (12 y)
Ziganshin et al[E4]	1995-2012	88% (1 y) 79% (3 y) 73% (6 y)
Michielon et al[28]	1996-2001	91.18% (9 y)
Pacini et al[29]	1978-2001	77.7% (5 y) 63% (10 y)
Hagl et al[E5]	1989-2000	95% (5 y) 93% (8 y)
Joo et al[E6]	1982-2010	90.4% (1 y) 82.7% (5 y) 77.6% (10 y) 65.3% (20 y) 60.3% (25 y)
Kalkat from the United Kingdom Heart Value Registry[25]	1986-2004	85.2% (1 y) 77.1% (5y) 70% (10y) 59.3% (20y)
Svensson et al[30]	1995-2011	Composite biological: 86% (5 y) 43% (15 y) Composite mechanical: 94% (5 y) 90% (10 y) 86% (15 y) Allograft: 92% (5 y) 83% (10 y) 74% (15 y)
Di Marco et al[31]	1978-2010	84.1% (5 y) 65.5% (10 y) 40.7% (20 y)
Hlavicka et al[E7]	2005-2018	75.4% ± 2.6% (1 y) 63.6 ± 3.0% (5 y) 46.2 ± 3.7% (10 y)
Karangelis et al[E8]	1999-2017	93.0% (6 mo) 93.0% (1 y) 89% (5 y) 73.0% (10, 15, and 18 y)