Are early outcomes of reoperative aortic root surgery impacted by previous root procedure and indication for reintervention?

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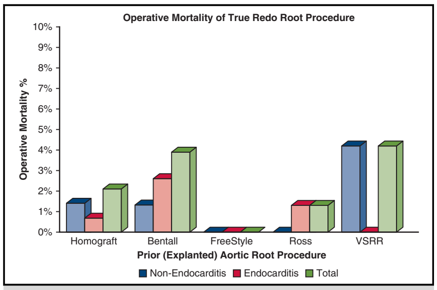
ABSTRACT

Objective: Reoperative aortic root surgery after a previous root procedure is technically demanding, which can impact outcomes. Herein, we examined the impact of previous root procedure and operative indication on early outcomes.

Methods: From January 2010 to December 2022, 632 patients underwent reoperative aortic root surgery after previous root procedure (true redo root) at our institution. Baseline characteristics, operative details, and in-hospital complications were compared between groups on the basis of type of previous root prosthesis and infective endocarditis indication.

Results: In the whole cohort, the operative mortality was 2.2% and estimated survival was 93%, 80%, and 67% at 1, 5, and 10 years, respectively. Operative mortality was similar between previous homograft, Bentall, Freestyle, valve-sparing root reimplantation, and Ross (2%, 4%, 0%, 4%, and 0%, respectively, $P = .4$). Reoperations after Bentall and valve-sparing root reimplantation (prosthetic grafts) had greater rates of postoperative complications, such as reoperation for bleeding (15% and 8%, $P = .01$), delayed chest closure (18% and 8%, $P = .02$), and pacemaker insertion (13% and 12%, $P = .03$). Although there was no significant difference in operative mortality among patients with endocarditis versus those with other indications (3% vs 1%, $P = .08$), the postoperative course showed greater rates of reoperation for bleeding (19% vs 5%, $P < .01$) and prolonged ventilation (38% vs 18%, $P < .01$).

Conclusions: At experienced centers, aortic root reoperation (true redo root) can be performed with low operative mortality. Explant of prosthetic graft material and endocarditis are associated with more complicated postoperative course, without significantly increased operative mortality. (JTCVS Open 2025;24:31-46)



Operative mortality by type of previous aortic root explant and endocarditis indication.

CENTRAL MESSAGE

Type of previous aortic root prosthesis and infective endocarditis indication impact the perioperative course of "true redo root" operations but not operative mortality at experienced aortic centers.

PERSPECTIVE

Aortic root replacement after previous aortic root surgery is technically demanding but has low mortality at an experienced center. Factors that can impact the early postoperative course but not mortality are explant of prosthetic aortic root graft and infective endocarditis. True redo root requires thorough preoperative assessment, careful planning, and meticulous technique for optimal outcomes.

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Received for publication Oct 17, 2024; revisions received Jan 18, 2025; accepted for publication Feb 5, 2025; available ahead of print March 12, 2025.

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2666-2736

https://doi.org/10.1016/j.xjon.2025.02.005

Abbreviations and Acronyms

CABG = coronary artery bypass grafting
CI = confidence interval
IQR = interquartile range
OR = odds ratio
VSRR = valve-sparing aortic root reimplantation

▶ Video clip is available online.

The management of aortic root pathologies such as aneurysm, dissection, and/or endocarditis has evolved significantly since the first reports of the Bentall procedure in 1968.[1] Aortic root replacement procedures now include valve-sparing aortic root re-implantation (VSRR), the Ross procedure, and aortic root replacement with aortic homograft or porcine stentless (eg, Freestyle, Medtronic) prosthesis.[1-3] Choice of operative approach depends largely on the indication for aortic root replacement, native aortic valve morphology, patient characteristics, and preference. With improving operative technique and perioperative care, outcomes after primary sternotomy aortic root replacement have improved, with an operative mortality of 2.2% for elective cases.[4] However, as this population increases in age and number, and with increasing rates of bioprosthetic use as the result of patient preference, more patients are presenting for reoperative aortic root replacement.[5] Other indications for reoperative aortic root replacement are aneurysmal degeneration of Ross autograft and infective endocarditis, with incidence on the rise.[6]

There are few reports from experienced centers about the outcomes of reoperative aortic root replacement in patients with previous aortic root surgery, or the true redo root.[5,7-10] Reoperation after previous aortic root surgery can be technically challenging as a result of dense scarring around the aortic root and coronary buttons.[9-11] One study using the Society of Thoracic Surgeons Adult Cardiac Surgery Database showed an operative mortality of 10.8% among patients undergoing reoperative aortic root replacement, although only 16.6% of those had had previous root surgery.[12] Reported operative mortality of true redo root at experienced centers range from 5% to 14%.[5,8,10,12]

In this study, we hypothesized that the complexity of true redo root procedures would be related in part to the type of previous aortic root prothesis or indication for reintervention. We aimed to test that hypothesis and characterize the technical challenges and outcomes of true redo root procedures in a large contemporary cohort.

METHODS

Study Cohort

All reoperative sternotomy aortic root replacements after previous homograft, Freestyle, Bentall (biological or mechanical prosthesis), VSRR, and Ross procedures performed at the Cleveland Clinic from January 2010 to December 2022 were queried. Chart review was performed to determine whether one of a patient's previous cardiac surgeries included previous aortic root procedure. Those who underwent aortic root replacement after previous aortic root replacement were included in the study cohort (true redo root). Exclusion criteria included age <18 years old, previous sternotomy for cardiac procedures other than aortic root procedure, and index redo aortic valve replacement. Baseline characteristics, procedural details, postoperative complications, and survival were collected from the Cleveland Clinic database and from chart review. All data were approved for use in research by the institutional review board on March 28, 2023, as Exempt Human Subject Research, with waiver of informed consent (#23-145).

Outcomes

The primary outcome was operative mortality after true reoperative aortic root replacement. Secondary outcomes included postoperative complications and survival stratified by the type of aortic root prosthesis explanted and operative indication.

Statistical Analysis

Baseline characteristics, procedural details, and in-hospital complications were compared by type of aortic root explant using Kruskal-Wallis and Dunn tests, whereas for endocarditis indication they were compared by using Wilcoxon 2-sample test for continuous variables. For categorical variables, χ^2 test of homogeneity and χ^2 test for independence were used for type of aortic root explant comparison, whereas the χ^2 test was used for endocarditis indication comparison. Data were tested for normality of distribution using Shapiro-Wilk test and Anderson-Darling test.

The Kaplan-Meier nonparametric method was used to analyze the estimated time to death after reoperative aortic root surgery overall, as well as compare estimated survival for patients with endocarditis versus those with other indications. Cox proportional hazard and multivariable logistic regression were performed to determine preoperative factors associated with worse survival, bleeding, prolonged ventilation, permanent pacemaker, and operative mortality. Data are presented as hazard ratio or odds ratio (OR) and 95% confidence interval (CI), Appendix E1.

Continuous variables were summarized as median (interquartile range [IQR]) and compared using Wilcoxon 2-sample test and Kruskal-Wallis test. Categorical variables are summarized by frequencies and percentages and compared using the χ^2 test and Fisher exact test when cell counts were small. Patients were censored at time of last known follow-up (Appendix E1). Median follow up was 2.5 years [IQR, 0.3-5.5 years]. Statistical analyses were performed using the SAS System for UNIX, 9.4 (SAS Institute).

RESULTS

Between January 2010 and December 2022, 632 patients were found to have undergone reoperative aortic root replacement after previous root replacement, or true redo root. The majority were male (n = 493; 78%) and White (n = 522; 82.6%), with a mean age of 55.2 ± 13.7 years. Previous aortic root procedures included 286 (44.9%) aortic homograft, 95 (14.9%) Freestyle root replacements, 151 (23.7%) Bentall procedures, 24 (3.8%) VSRR, and 76 (11.9%) Ross operations. Indications for reintervention included degenerative aortic valve pathology (regurgitation, n = 406, 63%; stenosis, n = 182, 28%), endocarditis (n = 176, 27.5%), and/or aortic root pathology (pseudoaneurysm, n = 70, 11%; and aneurysmal disease, n = 60, 9%), Table E1. *Streptococcus* species was the most common pathogen causing endocarditis, Table E2. The index true redo root procedure of the study included 216 (34.2%) root replacements with homograft, 26 (4.1%) Freestyle root replacements, 374 (59.2%) Bentall procedures, 14 (2.2%) VSRR, and 2 (0.3%) Ross procedures (Table 1). Surgery was elective in 60.0%, urgent in 39.2%, and emergent in 0.8%. The reoperation number was first redo in 56.9% (n = 360), second redo in 29.4% (n = 186), third redo 8.5% (n = 54), and fourth redo in 5% (n = 32). Cabrol grafts for coronary reimplantation were used in 5.7% (n = 36) of the cohort. There were 5 patients (0.8%) who underwent unplanned coronary artery bypass grafting (CABG) at the time of index surgery and 2 patients (0.3%) who underwent CABG during the same hospital admission. Mechanical circulatory support was necessary in 4.9% (n = 31) of cases (Tables 2 and E3). Median cardiopulmonary bypass time was 182 minutes [IQR, 145-228 minutes].

Overall operative mortality was 2.2% (n = 14) and estimated survival 93%, 80%, and 67% at 1, 5, and 10 years, respectively (Figure 1). Grouped by previous (original) root procedure, operative mortality after previous homograft, Bentall, Freestyle, VSRR, or Ross was 2.1% n = 6, 3.9% n = 6, 0% n = 0, 4.2% n = 1, and 1.3% n = 1, respectively, $P = .41$. Operations requiring explant of prosthetic surgical graft material (ie, reoperations after Bentall and VSRR) had greater overall rates of postoperative complications compared with explant of biologic grafts (ie, reoperations

TABLE 1. Baseline characteristics of the whole cohort (n = 632)

Variable	No. or median	Percentage (%) or interquartile range (IQR)
Demographics		
Race (White)	522	82.6%
Sex (female)	139	22%
Age, y	57	(47-65)
Body mass index	27.5	(24-31)
Comorbidities		
Diabetes	78	12.2%
Hypertension	457	71.7%
Dialysis	25	3.9%
Chronic lung disease	164	25.7%
Stroke	135	21.1%
Atrial fibrillation	174	27.3%
History of heart failure	169	26.7%
Left ventricle ejection fraction	56%	(50-60)
Moderate or greater right ventricular dysfunction	51	8%
Peripheral artery disease	69	10.9%
Previous root surgery		
Aortic homograft	286	44.9%
Bentall	151	23.7%
Freestyle	95	14.9%
Ross	76	11.9%
Valve-sparing root	24	3.8%
Index root surgery		
Aortic homograft	216	34.2%
Bentall	374	59.2%
Freestyle	26	4.1%
Ross	2	0.3%
Valve-sparing root	14	2.2%
Indication		
Aortic regurgitation	403	62.9%
Aortic stenosis	182	28.4%
Endocarditis	174	27.5%
Aortic root abscess	90	14%
Pseudoaneurysm	70	10.9%
Aortic aneurysm	60	9.4%

TABLE 2. Procedural variables by type of aortic root explant

Variable	Homograft n = 286	Bentall n = 151	Freestyle n = 95	Ross n = 76	Valve-sparing root n = 24	Total n = 632
Surgery status						
Elective	195 (68.2%)	49 (32.5%)	49 (51.6%)	66 (86.8%)	20 (83.3%)	379 (60.0%)
Urgent	89 (31.3%)	101 (66.9%)	44 (46.3%)	10 (13.2%)	4 (16.7%)	248 (39.2%)
Emergency	2 (0.7%)	1 (0.7%)	2 (2.1%)	0 (0%)	0 (0%)	5 (0.8%)
Reoperation						
First reoperation	145 (50.7%)	82 (54.3%)	64 (67.4%)	49 (64.5%)	20 (83.3%)	360 (56.9%)
Second reoperation	97 (33.9%)	44 (29.1%)	21 (22.1%)	21 (27.6%)	3 (12.5%)	186 (29.4%)
Third or more	44 (15.4%)	25 (16.5%)	10 (10.5%)	6 (7.9%)	1 (4.2%)	86 (13.6%)
Cabrol graft	12 (4.2%)	13 (8.6%)	5 (5.3%)	5 (6.6%)	1 (4.2%)	36 (5.7%)
Unplanned CABG	1 (0.3%)	4 (2.6%)	0 (0%)	0 (0%)	0 (0%)	5 (0.8%)
Planned CABG	38 (13.3%)	26 (17.2%)	12 (12.6%)	6 (7.9%)	3 (12.5%)	85 (13.4%)
Mitral repair	41 (14.3%)	27 (17.8%)	13 (13.7%)	11 (14.5%)	5 (20.8%)	97 (15.3%)
Mitral replacement	32 (11.2%)	11 (7.3%)	7 (7.4%)	3 (3.9%)	1 (4.2%)	54 (8.5%)
Tricuspid repair	43 (15.0%)	22 (14.6%)	11 (11.6%)	13 (17.1%)	1 (4.2%)	90 (14.2%)
Arch procedures*	12 (4%)	33 (22%)	13 (14%)	5 (6.6%)	4 (17%)	67 (11%)
CPB time, min	212 (IQR 164-263)	165 (IQR 131-208)	167 (IQR 140-220)	163 (IQR 136-192)	194 (IQR 136-328.5)	182 (IQR 159.5-201.5)
Any MCS	16 (5.6%)	10 (6.6%)	4 (4.2%)	0 (0%)	1 (4.2%)	31 (4.9%)
ECMO	12 (4.2%)	8 (5.3%)	1 (1.1%)	0 (0%)	0 (0%)	21 (3.3%)
IABP	8 (2.8%)	4 (2.6%)	3 (3.2%)	0 (0%)	1 (4.2%)	16 (2.5%)

CABG, Coronary artery bypass grafting; *CPB*, cardiopulmonary bypass; *IQR*, interquartile range; *MCS*, mechanical circulatory support; *ECMO*, extracorporeal membrane oxygenation; *IABP*, intra-aortic balloon pump. *Details of concomitant procedures in Table E4.

after homograft, Freestyle, and Ross), including reoperations for bleeding (15.4%, n = 23, and 8.1%, n = 2, *P* = .01), open chest at the index operation with planned delayed sternal closure (17.8%, n = 24, and 8.1% n = 2, *P* = .02), prolonged ventilation for >24 hours (33.6%, n = 50, and 33.3%, n = 8, *P* < .01), and pacemaker insertions (12.6%, n = 19, and 12.5%, n = 3, *P* = .03) (Table 3). Patients undergoing reoperation for homograft, xenografts, and autograft failures had significantly fewer complications, particularly those undergoing redo aortic root after Ross procedure (Table 3 and Appendix E2).

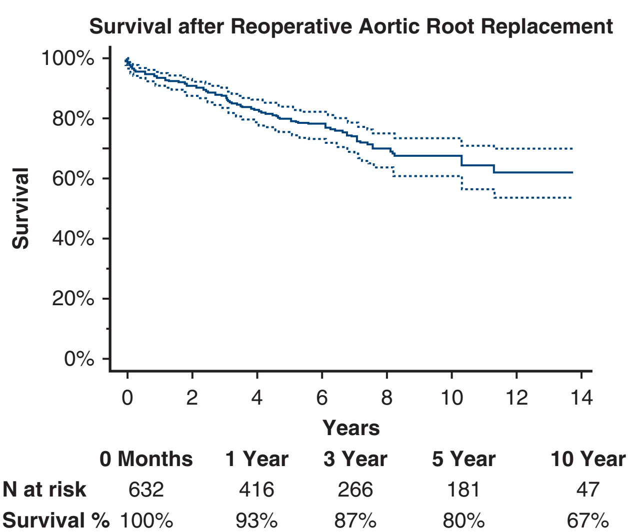


FIGURE 1. Kaplan-Meier estimate of survival after true redo root procedure for entire cohort.

Although there was no significant difference in the operative mortality among patients with endocarditis versus those with other indications (3.9%, n = 7, vs 1.5%, n = 7, *P* = .06), the postoperative course showed greater rates of reoperation for bleeding (19.4%, n = 34, vs 5.2%, n = 24, *P* < .01), delayed chest closure (16.1%, n = 28, vs 6.9%, n = 32, *P* < .01), prolonged ventilation (38.0%, n = 66, vs 18.3%, n = 85, *P* < .01), and longer intensive care unit stay (92 hours [IQR, 50.2-166 hours] vs 48 hours [IQR, 26.8-112.5 hours], *P* < .001) (Table 4). Endocarditis also was associated with worse long-term survival, with 1-, 5-, and 10-year survival rates at 84%, 64%, and 50% compared with respective survival rates of 96%, 85%, and 72% among those with other indications (*P* < .001) (Figure 2).

By multivariable regression analysis, cardiopulmonary bypass time (OR, 1.01; 95% CI, 1.0-1.02, *P* = .005) and perioperative extracorporeal membrane oxygenation (OR, 8.65; 95% CI, 1.4-47, *P* = .028) were independent risk factors of operative mortality. Endocarditis or type of previous root procedure were not a risk factors for operative mortality. Risk factors for re-exploration for bleeding were history

TABLE 3. Outcomes by type of aortic root explant

Variable	Homograft n = 286	Bentall n = 151	Freestyle n = 95	Ross n = 76	Valve-sparing root n = 24	*P* value*
Reoperation for bleeding	21 (7.3%)	23 (15.4%)	9 (9.5%)	2 (2.6%)	2 (8.1%)	.01
Delayed chest closure	24 (9.6%)	24 (17.8%)	6 (6.7%)	3 (4.5%)	2 (8.1%)	.02
Prolonged ventilation	58 (20.3%)	50 (33.6%)	27 (28.4%)	7 (9.2%)	8 (33.3%)	<.01
Postoperative pacemaker	19 (6.7%)	19 (12.6%)	10 (10.5%)	1 (1.3%)	3 (12.5%)	.02
Stroke	5 (1.7%)	3 (1.9%)	2 (2.1%)	2 (2.6%)	0 (0%)	.91
Intensive care unit stay (median hours)	54 [IQR, 29-113]	91 [IQR, 47-169]	70 [IQR, 42-158]	35 [IQR, 22-49]	80 [IQR, 45-144]	<.01
Operative mortality	6 (2.1%)	6 (3.9%)	0 (0%)	1 (1.3%)	1 (4.2%)	.41

IQR, Interquartile range. *Intergroup comparisons using χ^2 test of independence are in Appendix E2.

of stroke (OR, 2.06; 95% CI, 1.09-3.9, *P* = .024), cardiopulmonary bypass time (OR, 1.06; 95% CI, 1.02-1.12; *P* < .001), and perioperative extracorporeal membrane oxygenation (OR, 14.6; 95% CI, 4.96-46; *P* < .001). Risk factors for postoperative pacemaker were previous Bentall (OR, 2.3; 95% CI, 1.09-4.85, *P* = .02) and emergency surgery (OR, 5.34; 95% CI, 1.97-26.6, *P* = .03), Appendix E1 (Models 1-5).

DISCUSSION

Principle Findings

Operative mortality of true redo root procedures in experienced hands is low. Operations requiring explant of prosthetic graft material and endocarditis are associated with more postoperative complications; however, operative mortality was not significantly increased. True root redo performed for infective endocarditis is associated with worse survival.

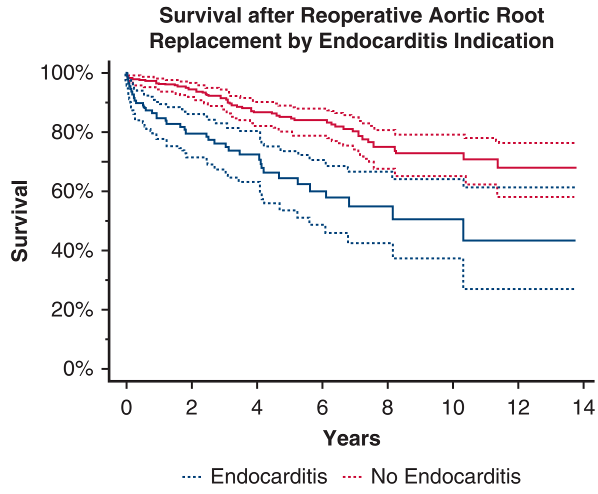
Outcomes of Redo Root Replacement After Previous Aortic Root Procedure

In an Society of Thoracic Surgeons study reported by Ogami and colleagues,[12] operative mortality of any redo sternotomy aortic root replacement was 10.8%, with only 16.6% of those being true redo root procedures. The number of previous sternotomies and lower institutional volume was associated with worse survival. True redo root procedure, interestingly, was not associated with worse survival, but these patients were younger with fewer comorbidities.[12] El-Hamamsy and colleagues[10] examined the outcomes of 84 true redo root procedures and showed a 30-day mortality rate of 2.4%. Garrido-Olivares and colleagues[1] reported 84 true redo root procedures with an operative morality of 6%. Jassar and colleagues[5] studied 120 true redo root procedures and reported an operative mortality of 5% for the whole cohort. For those with endocarditis, operative mortality was 9% and for degenerative valve failure it was 3%, which was not significant. Patel and colleagues[8] compared a cohort of 184 true redo root patients with a cohort of 638 aortic root procedures following any other previous cardiac surgery, and true redo root operations had an in-hospital mortality of 13%, which was not statistically different from the other group. The operative mortality in our study of 632 procedures was 2.2%. Operative mortality was not affected by type of previous aortic prosthesis explant or indication for surgery.

TABLE 4. Outcomes by endocarditis indication for index redo aortic root surgery

Variable	Endocarditis indication n = 174	Other indication n = 458	*P* value
Reoperation for bleeding	34 (19.4%)	24 (5.2%)	<.01
Delayed chest closure	28 (16.1%)	32 (6.9%)	.01
Prolonged ventilation	66 (38.0%)	85 (18.3%)	<.01
Postoperative pacemaker	17 (9.7%)	35 (7.7%)	.44
Stroke	4 (2.3%)	8 (1.7%)	.64
Sepsis	5 (2.9%)	3 (0.7%)	.04
Intensive care unit stay (median hours)	92 [IQR, 50-166]	48 [IQR, 27-112]	<.01
Operative mortality	7 (3.9%)	7 (1.5%)	.06

IQR, Interquartile range.



	0 Month		1 Year		3 Years		5 Years		10 Years	
Endocarditis	No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
N at risk	456	176	322	95	228	64	150	32	40	8
Survival%	100%		96%	84%	91%	76%	85%	64%	72%	50%

FIGURE 2. Kaplan-Meier estimate of survival after true redo root procedure for endocarditis versus any other indication.

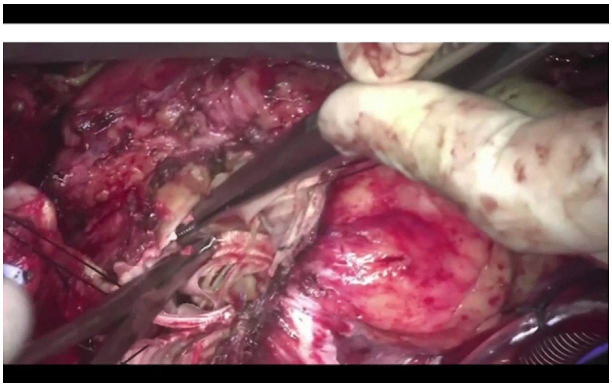
Are True Redo Root Procedures Influenced by Type of Previous Aortic Root Prosthesis?

The patients who underwent explant of prosthetic aortic grafts experienced greater rates of postoperative bleeding, delayed chest closure, pacemaker placement, and prolonged ventilation compared with explant of biologic material (homograft, Freestyle, and Ross). However, these complications did not result in a greater operative mortality.

Compared with biologic material, prosthetic aortic grafts (used in VSRR and Bentall procedures) stimulate development of a thick rind of scar tissue around the graft. This rind may allow for easier mobilization of the graft itself, but the surrounding scar tissue renders the mobilization of the coronary buttons challenging.[9] Extensive dissection of scar tissue may lead to increased bleeding and greater pacemaker rates as the result of debridement along the left ventricular outflow tract. Biologic roots like homograft and xenograft induce less of an inflammatory response and present fewer adhesions. Although these conduits calcify with time,[13,14] they offer easier dissection as the calcified wall can be used to guide for dissection. Xenografts contain prosthetic sewing cuff but is associated with less scarring around the biological walls.

In the setting of dense scarring around previous aortic root prosthesis, complications from coronary button reimplantation can contribute to early mortality. Need for unplanned CABG at time of redo root procedures was associated with operative and late mortality in the study by Jassar and colleagues.[5] One single-center, retrospective study observed 4.3% unplanned CABG at the time of primary aortic root replacement; however, unplanned CABG did not impact operative or long-term mortality.[15] The right coronary button is more prone to kinking, and if right ventricular function remains depressed after adequate deairing, CABG should be performed to the right coronary artery.[16] Dissection of the left coronary button off the right pulmonary artery is difficult, as this plane is less well-defined (Video 1). If the left coronary button is fragile, stuck in dense scarring, or too short for direct reimplantation in the new root prosthesis, one alternative is creating a Cabrol graft.[17] In our study, 6% received Cabrol grafts.

The experiences of rescuing patients from coronary complications in our study are instructive. Five patients underwent unplanned intraoperative CABG. Four were for right



VIDEO 1. Case presentation of a true redo root procedure for subacute endocarditis after previous Bio-Bentall procedure. Video available at: https://www.jtcvs.org/article/S2666-2736(25)00052-X/fulltext.

ventricular dysfunction, which resolved with vein graft bypass to right coronary artery. One patient undergoing composite graft explant had friable coronary buttons and required sacrifice of the native coronary buttons with 3-vessel bypass grafting. Two patients were taken back to the operating room during their same admission for CABG. One patient had right ventricular dysfunction, whereas the other was found to have left main coronary stenosis.

Are True Redo Root Procedures Influenced by Indication for Reintervention?

Infective endocarditis was associated with a more complicated postoperative course, with greater rates of bleeding, delayed chest closure, prolonged ventilation, and intensive care unit stay. However, endocarditis was not a risk factor for worse outcomes in our study. Numerous studies have supported the substantial morbidity and mortality associated with infective endocarditis despite medical and surgical therapies.[18] Prosthetic valve endocarditis demands explant of all infected foreign material with debridement to healthy tissue.[19] For patients with previous aortic root replacement, excision of root prosthesis is challenging in an acute inflammatory state, particularly with aortic root abscess. Our preferred prosthesis for reconstruction of the aortic root in case of aortic root abscess is an aortic homograft, as it can be directly implanted into the fragile left ventricular outflow tract and has better resistance to recurrent infection.[20]

Postoperative course in patients with prosthetic valve endocarditis is often complicated by vasoplegia and/or coagulopathy secondary to prolonged cardiopulmonary bypass time and a systemic inflammatory response,[21] accounting for the greater rates of reoperation for bleeding and delayed chest closure. Although these complications were not associated with operative mortality, there was a significantly worse long-term survival in patients with endocarditis versus those without. Jassar and colleagues[5] demonstrated that the operative mortality rate was greater and survival rates worse in patients with an infection indication compared to degenerative valve indication. Similarly, Heubner and colleagues[22] showed that among reoperative aortic root replacement patients, active endocarditis was an independent risk factor for mortality.

Technical Considerations for True Redo Root Procedures

The keys to success for complex redo cardiac surgery are (1) thorough preoperative evaluation and imaging, (2) careful surgical planning (particularly strategies for re-entry, myocardial and cerebral protection), and (3) meticulous technique in dissecting out the aortic root and mobilization of the coronary buttons (Video 1).

Our cannulation strategy for patients with unsafe re-entry on the basis of preoperative imaging is peripheral cannulation via the axillary artery and femoral vein; however, central cannulation can be undertaken if deemed amendable. For myocardial protection, we use antegrade and direct retrograde cardioplegia for optimal delivery. The coronary buttons are cut out and mobilized early from the aortic valve prosthesis to avoid injury. Careful dissection of the right pulmonary artery from the posterior aspect of the aortic root defines the dissection plane and allows adequate mobilization of left coronary button. Mobilization of the right coronary artery is less tedious. Preserving the integrity of the tissues while explanting the previous prosthesis is key for proper seating of the new prosthesis to avoid bleeding complications and development of pseudoaneurysms. We have a low threshold to replace the entire root rather than aortic valve replacement in cases of low implantation of coronary buttons, degenerated homograft or xenograft for concerns regarding the annulus integrity, and to avoid patient-prosthesis mismatch. In addition, pseudoaneurysm of coronary button or aortic suture line might not be amendable for simple repair and require replacement of the entire root for optimal long-term outcomes. We avoid routine use of surgical felt or hemostatic agents, as they do not allow proper testing of the suture lines and may result in late development of pseudoaneurysms (Video 1).

Limitations

Although this study provides insight into the short and long-term outcomes of reoperative aortic root replacement, there are inherent limitations. This is a single-center, retrospective study and limited by its observational nature, which is subject to internal bias. Although we were able to obtain granular details of operative interventions, details such as frailty and clinical status at time of presentation are limited. Furthermore, the size of our subgroups by valve explant type limited the ability to perform an adjusted comparison of groups. Despite these limitations, we were able to analyze outcomes of reoperative aortic root replacement and understand the implications of prosthesis explant type and operative indication on perioperative morbidity and mortality.

CONCLUSIONS

With the growing experience with different primary aortic root procedures, more patients are expected to present with failing or infected aortic prostheses requiring reoperation. Although technically challenging, true redo root procedures can be performed with low operative mortality. Explant of aortic root prosthetic grafts and reoperations for endocarditis are associated with more complicated postoperative course. Successful outcomes of true redo root operations require thorough preoperative evaluation, careful surgical planning, and meticulous technique.

Conflict of Interest Statement

Dr Elgharably has financial relationships with Edwards Lifesciences, Artivion, and LifeNet Health. Dr Roselli has financial relationships with Artivion, Edwards Lifesciences, Medtronic, LifeNet Health, and Terumo Aortic. 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: aortic root replacement, cardiac reoperation, homograft, infective endocarditis

APPENDIX E1. Variables used in the uni- and multivariable analysis

Variable	Available, n*
Baseline/preoperative variables	
Age	632
Body mass index	632
Comorbidities	
Smoking	620
Hypertension	632
Diabetes	632
Chronic lung disease	632
Renal failure requiring dialysis	626
Peripheral arterial disease	632
Cerebrovascular disease	632
Cardiac comorbidities	
History of myocardial infarction	632
History of heart failure	632
History of previous coronary artery bypass grafting	632
Preoperative left ventricular ejection fraction %	632
Preoperative right ventricular function	632
Indications for surgery	
Type of previous aortic root procedure	632
Aortic regurgitation	632
Aortic stenosis	632
Aortic aneurysm	632
Pseudoaneurysm	632
Infective endocarditis	632
Operative variables	
Type of index redo root operation (true redo root)	632
Aortic root abscess	632
Organism causing endocarditis	632
Surgery status (elective, urgent, emergency)	632
Number of redo surgery	632
Total cardiopulmonary bypass time	632
Technique of coronary button (reimplantation, Cabrol graft)	632
Concomitant procedures	
Planned coronary artery bypass grafting	632
Unplanned coronary artery bypass grafting	632
Mitral valve repair	632
Mitral valve replacement	632
Tricuspid valve repair	632
Tricuspid valve replacement	632
Pulmonic valve replacement	632
Arch procedures	632
Postoperative variables	
Postoperative prolonged mechanical ventilation (>48 h)	632
Postoperative sepsis	632
Postoperative gastrointestinal complications	632
Postoperative stroke	632
Postoperative renal dysfunction requiring dialysis	632
Re-exploration for bleeding	632
Extra-corporeal membrane oxygenator insertion	632
Postoperative conduction disturbance requiring pacemaker	632

*Available n: Patients with data available.

MODEL 1. Risk factors for survival with statistical significance*

Variable	Hazard ratio	Lower CI	Upper CI	*P* value
Baseline/preoperative variables				
Age	1.02	2.72	2.81	**.02**
Operative variables				
Technique of coronary button	1.41	1.24	2.19	**.006**
Mitral valve replacement	1.12	1.89	7.24	.687
Pulmonic valve replacement	1.28	1.08	2.56	**.039**
Surgery number	1.18	2.57	4.38	.139
Total cardiopulmonary bypass time	1.00	2.71	2.73	**.029**
Postoperative variables				
Postoperative prolonged mechanical ventilation (>48 h)	2.57	5.06	59.32	<**.001**
Postoperative sepsis	0.75	1.21	18.13	.681
Postoperative gastrointestinal complications	0.55	1.23	4.39	.240
Re-exploration for bleeding	1.00	1.73	6.19	.995
Extracorporeal membrane oxygenator insertion	1.36	1.74	29.26	.497

Patients were censored at time of last known follow up. Long-term mortality was not validated with the Centers for Disease Control and Prevention National Death Index. Time of last known follow up is recorded from follow up documentation at Cleveland Clinic or outside medical centers, and phone call documentation as part of Cleveland Clinic follow up program or the patient's family contacting Cleveland Clinic. Patients with missing follow-up data were excluded from the analysis. *P* values in bold are statistically significant. *CI*, Confidence interval. *Using the backward selection logistic regression approach, multivariable analysis was performed on significant variables ($P < .05$) identified in univariable analysis. The retention and significance criteria for variables in multivariable analysis was set at $P < .05$.

MODEL 2. Risk factors for operative mortality with statistical significance*

Variable	Odds ratio	Lower CI	Upper CI	*P* value
Baseline/preoperative variables				
Type of previous aortic root procedure				
Bentall	0.50	0.075	2.65	.43
Ross	2.02	0.090	19.50	.57
Valve-sparing root	2.95	0.124	29.14	.39
Infective endocarditis	1.29	0.21	7.94	.77
Operative variables				
Unplanned coronary artery bypass grafting	14.52	0.61	29.31	.078
Index root operation				
Bentall	0.98	0.10	7.26	.99
Bio-Bentall	1.18	0.13	9.76	.87
Freestyle	0.55	0.02	21.6	.80
Surgery status				
Urgent	2.36	0.366	14.87	.350
Emergent	0.72	0.003	4.12	.997
Mitral valve replacement	3.90	0.626	20.09	.110
Total cardiopulmonary bypass time	1.01	1.00	1.016	**.005**
Postoperative variables				
Re-exploration for bleeding	0.81	0.09	20.2	.559
Extracorporeal membrane oxygenator insertion	8.65	1.37	47.3	**.028**

P values in bold are statistically significant. *CI*, Confidence interval. *Using the backward selection logistic regression approach, multivariable analysis was performed on significant variables ($P < .05$) identified in univariable analysis. The retention and significance criteria for variables in multivariable analysis was set at $P < .05$.

MODEL 3. Risk factors for prolonged mechanical ventilation (>24 hours) after surgery with statistical significance*

Variable	Odds ratio	Lower CI	Upper CI	*P* value
Baseline/preoperative variables				
Chronic lung disease	2.19	1.35	3.57	**<.001**
History of peripheral arterial disease	2.16	1.11	4.15	**.020**
History of cerebrovascular disease	2.53	1.60	4.01	**<.001**
History of myocardial infarction	2.80	1.43	5.43	**.002**
History of heart failure	1.00	0.62	1.61	.983
History of previous coronary artery bypass grafting	1.00	0.50	1.95	.979
Operative variables				
Total cardiopulmonary bypass time	1.00	1.00	1.01	**.05**
Planned coronary artery bypass grafting	1.32	0.71	2.39	.35
Mitral valve replacement	1.61	0.89	2.87	.106
Postoperative variables				
Postoperative gastrointestinal complications	3.31	1.28	8.58	**.012**
Postoperative stroke	2.64	0.51	13.95	.240
Postoperative renal dysfunction requiring dialysis	27.7	4.68	34.83	**.002**
Extracorporeal membrane oxygenator insertion	3.59	0.85	19.38	.099

P values in bold are statistically significant. *CI*, Confidence interval. *Using the backward selection logistic regression approach, multivariable analysis was performed on significant variables ($P < .05$) identified in univariable analysis. The retention and significance criteria for variables in multivariable analysis was set at $P < .05$.

MODEL 4. Risk factors for re-exploration for bleeding with statistical significance*

Variable	Odds ratio	Lower CI	Upper CI	*P* value
Baseline/preoperative variables				
Type of previous aortic root procedure				
Bentall	1.66	0.78	3.54	.180
Freestyle	1.56	0.60	3.79	.333
Ross	0.73	0.10	2.85	.692
Valve sparing root	1.08	0.14	5.05	.925
History of cerebrovascular disease	2.06	1.09	3.90	**.024**
History of myocardial infarction	2.17	0.92	4.86	.064
History of heart failure	1.13	0.58	2.16	.707
History of previous coronary artery bypass grafting	1.20	0.49	2.67	.667
Operative variables				
Total cardiopulmonary bypass time	1.06	1.02	1.12	**<.001**
Postoperative variables				
Extracorporeal membrane oxygenator insertion	14.6	4.96	46.0	**<.001**

P values in bold are statistically significant. *CI*, Confidence interval. *Using the backward selection logistic regression approach, multivariable analysis was performed on significant variables ($P < .05$) identified in univariable analysis. The retention and significance criteria for variables in multivariable analysis was set at $P < .05$.

MODEL 5. Risk factors for permanent pacemaker implantation mortality with statistical significance*

Variable	Odds ratio	Lower CI	Upper CI	*P* value
Baseline/preoperative variables				
Type of previous aortic root procedure				
Bentall	2.30	1.09	4.85	**.02**
Freestyle	1.69	0.71	3.82	.21
Ross	0.20	0.01	1.01	.12
Valve-sparing root	2.06	0.44	6.97	.28
Operative variables				
Surgery status				
Urgent	0.59	0.29	1.13	.11
Emergency	5.34	1.97	26.6	**.03**
Mitral valve replacement	1.77	0.85	3.47	.10
Total cardiopulmonary bypass time	1.00	0.99	1.00	1.19

P values in bold are statistically significant. *CI*, Confidence interval. *Using the backward selection logistic regression approach, multivariable analysis was performed on significant variables ($P < .05$) identified in univariable analysis. The retention and significance criteria for variables in multivariable analysis was set at $P < .05$.

APPENDIX E2. Results of Kruskal-Wallis and Dunn Tests for total ICU hours by aortic root explant type

ICU stay by type of aortic root explanted analyzed by Kruskal-Wallis test						
Variable	**Homograft n = 286**	**Bentall n = 151**	**Freestyle n = 95**	**Ross n = 76**	**Valve-sparing root n = 24**	***P* value**
ICU stay (median hours)	54 [IQR, 29-113]	91 [IQR, 47-169]	70 [IQR, 42-158]	35 [IQR, 22-49]	80 [IQR, 45-144]	**<.01**

Comparison	***P* value**
ICU stay by type of aortic root explanted analyzed by Dunn Test	
Bentall vs aortic homograft	**<.001**
Valve sparing aortic root replacement vs aortic homograft	.0859
Freestyle prothesis vs aortic homograft	**.0239**
Valve-sparing aortic root replacement vs Ross	**<.001**
Valve-sparing aortic root replacement vs Freestyle prothesis	.8164
Valve-sparing aortic root replacement vs Bentall	.5674
Freestyle prothesis vs Bentall	.2284
Ross vs Freestyle prothesis	**<.001**
Ross vs Bentall	**<.001**
Ross vs aortic homograft	**<.001**
Reoperation for bleeding by type of aortic root explanted analyzed by χ^2 test of independence	
Aortic homograft vs Bentall	**.014**
Aortic homograft vs Freestyle prosthesis	.654
Aortic homograft vs Ross	.209
Aortic homograft vs valve-sparing root replacement	.980
Bentall vs Freestyle prosthesis	.265
Bentall vs Ross	**.007**
Bentall vs valve-sparing root replacement	.607
Freestyle prosthesis vs Ross	.128
Freestyle prosthesis vs valve-sparing root replacement	.998
Ross vs valve-sparing root replacement	.481
Delayed chest closure by type of aortic root explanted analyzed by χ^2 test of independence	
Aortic homograft vs Bentall	**.026**
Aortic homograft vs Freestyle prosthesis	.185
Aortic homograft vs Ross	.275
Aortic homograft vs valve-sparing root replacement	.998
Bentall vs Freestyle prosthesis	**.041**
Bentall vs Ross	**.014**
Bentall vs valve-sparing root replacement	.556
Freestyle prosthesis vs Ross	.715
Freestyle prosthesis vs valve-sparing root replacement	.993
Ross vs valve-sparing root replacement	.702
Stroke by type of aortic root explanted analyzed by χ^2 test of independence	
Aortic homograft vs Bentall	.993
Aortic homograft vs Freestyle prosthesis	.992
Aortic homograft vs Ross	.988
Aortic homograft vs valve-sparing root replacement	.997
Bentall vs Freestyle prosthesis	.992
Bentall vs Ross	.990
Bentall vs valve-sparing root replacement	.996
Freestyle prosthesis vs Ross	.978
Freestyle prosthesis vs valve-sparing root replacement	.977
Ross vs valve-sparing root replacement	.980

(Continued)

APPENDIX E2. Continued

Comparison	*P* value
Prolonged ventilation (>24 h) by type of aortic root explanted analyzed by χ^2 test of independence	
Aortic homograft vs Bentall	**.004**
Aortic homograft vs Freestyle prosthesis	.131
Aortic homograft vs Ross	**.035**
Aortic homograft vs valve-sparing root replacement	.376
Bentall vs Freestyle prosthesis	.527
Bentall vs Ross	**.001**
Bentall vs valve-sparing root replacement	.986
Freestyle prosthesis vs Ross	**.002**
Freestyle prosthesis vs valve-sparing root replacement	.997
Ross vs valve-sparing root replacement	**.024**
Postoperative pacemaker by type of aortic root explanted analyzed by χ^2 test of independence	
Aortic homograft vs Bentall	.055
Aortic homograft vs Freestyle prosthesis	.310
Aortic homograft vs Ross	.122
Aortic homograft vs valve-sparing root replacement	.467
Bentall vs Freestyle prosthesis	.776
Bentall vs Ross	**.009**
Bentall vs valve-sparing root replacement	.998
Freestyle prosthesis vs Ross	**.031**
Freestyle prosthesis vs valve-sparing root replacement	.980
Ross vs valve-sparing root replacement	.055
Operative mortality by type of aortic root explanted analyzed by χ^2 test of independence	
Aortic homograft vs Bentall	.404
Aortic homograft vs Freestyle prosthesis	.343
Aortic homograft vs Ross	.990
Aortic homograft vs valve-sparing root replacement	.997
Bentall vs Freestyle prosthesis	.122
Bentall vs Ross	.483
Bentall vs valve-sparing root replacement	.990
Freestyle prosthesis vs Ross	.915
Freestyle prosthesis vs valve-sparing root replacement	.439
Ross vs valve-sparing root replacement	.942

P values in bold are statistically significant. *ICU*, Intensive care unit; *IQR*, interquartile range.

TABLE E1. Indications for reoperative aortic root replacement by previous/explanted aortic root type

Previous aortic root procedure*	Indications for redo aortic root procedure				
		Nonendocarditis (n = 458)			
	Endocarditis (n = 174)	Aortic valve stenosis	Aortic valve regurgitation	Aortic Aneurysm	Pseudoaneurysm†
Homograft (n = 286)	43	105	209	Total 4: 3 Ascending/arch 1 Homograft dilation	Total 8: 7 Proximal suture line 1 Distal suture line
Bentall (n = 151)	85	35	17	2 Ascending/arch	Total 20: 10 Proximal suture line 6 Distal suture line 4 Coronary button
Freestyle (n = 95)	36	23	40	5 Ascending/arch	Total 9: 6 Proximal suture line 3 Distal suture line
Ross (n = 76)	2	4	72	43 Aortic root aneurysms (failed Ross)	0
VSRR (n = 24)	8	0	12	3 Ascending/arch	Total 4: 2 Proximal suture line 1 Distal suture line 1 Coronary button

VSRR, Valve-sparing aortic root reimplantation. *Limited granular data were available for the first aortic root operations performed at other institutions. †Pseudoaneurysm location: Proximal suture line indicates the suture line along the aortic annulus/left ventricular outflow tract; distal suture line indicates the graft to native aortic anastomosis; coronary button pseudoaneurysms involve the coronary button to aortic prosthesis suture line.

TABLE E2. Pathogens identified in the endocarditis cohort (n = 174)

Micro-organism	n (%)
Streptococcus	39 (22.4%)
Staphylococcus aureus	32 (18.3%)
Coagulase-negative staphylococcus	15 (8.6%)
Enterococcus	17 (10%)
Fungal	10 (5.7%)
Other	31 (18%)
Culture negative	30 (17%)

TABLE E3. Perioperative mechanical circulatory support (MCS, n = 31)

Timing of MCS	Type of MCS	Indication
Intraoperative (at conclusion of surgery, n = 17)	VA ECMO = 12	Postpump ventricular dysfunction = 9 (including 3 cases with unplanned CABG for calcified or fragile coronary buttons) Pulmonary edema, secondary RV dysfunction = 3
	VV ECMO = 5	Post-pump pulmonary edema = 5
Postoperative (n = 4)	VA ECMO = 3	ECMO CPR = 1 Pulmonary edema, secondary RV dysfunction = 2
	VV ECMO = 1	Respiratory failure = 1
Intraoperative (at conclusion of surgery, n = 10)	IABP	Ventricular arrythmia postpump (including unplanned CABG) = 1 Hemodynamic instability (increased pharmacological support) = 5 Assist in weaning of cardiopulmonary bypass = 4
Postoperative (n = 6)	IABP	Ventricular arrythmia = 1 Hemodynamic instability (increased pharmacological support) = 5

MCS, Mechanical circulatory support; *VA*, venoarterial; *ECMO*, extracorporeal membrane oxygenator; *CABG*, coronary artery bypass grafting; *RV*, right ventricle; *VV*, venovenous; *CPR*, cardiopulmonary resuscitation; *IABP*, intra-aortic balloon pump.

TABLE E4. Concomitant procedures in the overall cohort (n = 632)

Concomitant procedures	Available, n*	n (%)
Coronary artery bypass grafting	632	
Planned		85 (13%)
Unplanned		5 (1%)
Mitral valve surgery	632	
Mitral valve repair		96 (15%)
Mitral valve replacement		53 (8%)
Reconstruction of the inter-valvular fibrosa†	632	
Commando		11 (2%)
Hemi-Commando		6 (1%)
Tricuspid valve surgery	632	
Tricuspid valve repair		91 (14%)
Tricuspid valve replacement		4 (0.6%)
Pulmonic valve replacement	632	
Biological valve + RVOT pericardial patch		2 (0.3%)
Mechanical valve + RVOT pericardial patch		1 (0.2%)
Biological composite graft		2 (0.3%)
Mechanical composite graft		1 (0.2%)
Allograft		22 (3.5%)
Autograft (reverse Ross)‡		29 (4.6%)
Arch surgery	632	
Hemiarch		46 (7%)
Hemiarch + frozen elephant trunk		2 (0.3%)
Total arch replacement		6 (1%)
Total arch replacement + frozen elephant trunk		13 (2%)
Other	632	
Ablation		16 (2.5%)
Pericardiectomy		2 (0.3%)
Septal myectomy		2 (0.3%)
Resection of subaortic membrane		2 (0.3%)

RVOT, Right ventricular outflow tract. *Available n: patients with data available. †Description of Commando & Hemi-Commando procedures: Navia JL, Elgharably H, et al. Long-term outcomes of surgery for invasive valvular endocarditis involving the aortomitral fibrosa. *Ann Thorac Surg*. 2019;108(5):1314-1323. ‡Description of Reverse Ross: Weiss and Pettersson. The Ross reversal. *J Thorac Cardiovasc Surg Tech*. 2021;10:417-422.