True redo-aortic root replacement versus root replacement after any previous surgery

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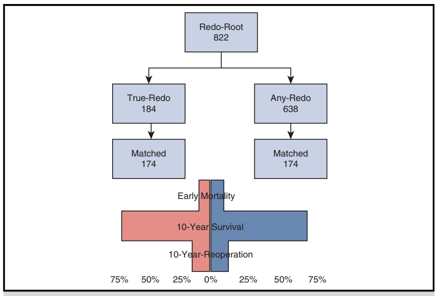
ABSTRACT

Objective: The impact of previous aortic root replacement (True-Redo) versus any previous operation (Any-Redo) on outcomes after reoperative aortic root replacement (redo-ROOT) is largely unknown. In this first multi-institutional study, the clinical impact True-Redo versus Any-Redo in the setting of redo-ROOT was reviewed.

Methods: From 2004 to 2021, 822 patients underwent redo-ROOT at 2 major academic centers: 638 Any-Redo and 184 True-Redo. Matching based on preoperative demographics and concomitant operations resulted in 174 matched pairs. An independent risk factor analysis was performed to determine risk factors for early and late mortality.

Results: Patients in the True-Redo group were younger, at 49.9 ± 15.1 versus 55.3 ± 14.7 years, $P < .001$. Concomitant operations were largely similar between the 2 groups, $P > .05$. Median cardiopulmonary bypass time ($P < .001$) and aortic crossclamp time ($P = .03$) were longer for True-Redo group. In-hospital mortality was 13% (109) and was without significant difference between groups, $P = .41$. Ten-year survival was 78% versus 76% for True-Redo versus Any-Redo groups respectively, $P = .7$. Landmark survival analysis at 4 years' postoperatively on the matched groups found that patients in the True-Redo group had improved survival outcomes ($P = .046$). Risk factors of in-hospital mortality consisted of older age ($P < .0001$), lower ejection fraction ($P = .02$), and male patient ($P = .0003$).

Conclusions: Clinical outcomes following redo-ROOT are excellent. Performance of a True-Redo-ROOT does not result in worse in-hospital morbidity or mortality and has improved survival benefit at midterm follow-up when compared with patients in the Any-Redo group. The decision to perform a redo-ROOT must be taken seriously and must be individualized in a patient-specific manner for optimal outcomes. (JTCVS Open 2023;16:167-76)



Study design of 822 patients divided by 184 True-Redo and 638 Any-Redo groups with 174 matched pairs. Early mortality, 10-year survival, and 10-year reoperation rate are similar.

CENTRAL MESSAGE

Redo aortic root replacement after previous root replacement or any prior cardiac operations has excellent clinical outcomes and can be performed safely in select patients at centers of excellence.

PERSPECTIVE

The significance of the specific type of prior cardiac surgery affecting morbidity and mortality of a redo-aortic root replacements is unclear. This multi-institutional study demonstrated that outcomes following redo-aortic root replacement are excellent without significance differences in-hospital morbidity or mortality between True-Redo versus Any-Redo patients.

Aortic root replacement (ROOT) in the surgical treatment of aortic root pathology has become a safe and effective option in the modern era, with elective operative mortality ranging from 1% to 4%.[1,2] Indications for aortic root reintervention resulting from complications of ROOT include structural degeneration, endocarditis, or false aneurysms.[3,4]

Reoperative cardiac surgeries are complex procedures associated with significant risks and challenges. Previous

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Abbreviations and Acronyms
- CI = confidence interval
- IQR = interquartile range
- IRB = institutional review board
- ROOT = aortic root replacement

studies of reoperative ROOT after any previous cardiac surgery report operative mortality ranging from 7% to 14%,[5-8] with long-term mortality rates ranging 12% to 26%.[5,8] The identified risk factors include age, New York Heart Association class, concomitant mitral valve surgery, as well as preoperative comorbidities of previous myocardial infarction and chronic lung disease.[5,6,8] Patients undergoing reoperative ROOT after previous root replacement ("true" redo root replacement) have demonstrated increased operative mortality up to 12%, although other series have reported operative deaths as low as 3%.[3,4,9-11] Five-year survival rates after true redo root replacement have been reported from 71% to 89%.[3,10,11]

In examining redo ROOT (Redo-Root), however, there is a paucity of data surrounding the differences in outcome based on previous cardiac surgical history. In the setting of Redo-Root, the direct impact of previous ROOT (True-Redo) on outcomes compared with any previous cardiac operation (Any-Redo) is presently unclear. This multi-institutional study aimed to assess and compare the clinical outcomes of True-Redo versus Any-Redo operation in the setting of redo ROOT.

METHODS

Patients

We retrospectively queried the institutional Society of Thoracic Surgeons databases of 2 major academic centers to identify patients who underwent redo sternotomy and ROOT from January 2004 to February 2021. A total of 822 consecutive patients met inclusion criteria and were divided based on their previous surgical history. Of these, 184 patients underwent true redo ROOTs, whereas 638 patients underwent ROOT in the setting of a redo sternotomy secondary following a variety of previous cardiac surgery procedures. These cases were performed by all institutional surgeons.

Demographic information, medical and surgical history, perioperative course, and long-term follow-up data were collected through the electronic medical records. The primary end point was in-hospital mortality. Secondary end points were early postoperative hospital metrics, late mortality, and reoperation. Early events were defined as those occurring during the operative stay or within 30 days of the discharge and late events for all events outside of this time period. Long-term follow-up was obtained by a combination electronic medical review and select querying of the Centers for Disease Control and Prevention National Death Index (accessed for data through December 31, 2020). Follow-up was collected between January 1, 2019, and December 31, 2021, and was considered complete if patient status was confirmed during this time and was 84% complete with this criterion.

Data Analysis

This study was approved by the Columbia University Institutional Review Board (IRB#: AAAU0575; most recent approval date: April 4, 2022) and the Emory University IRB (IRB#: 00001479; most recent approval date: August 30, 2021). This study was compliant with the Health Insurance Portability and Accountability Act and the Declaration of Helsinki. Need for individual patient consent was waived, given that all data were retrospectively collected. All statistics were performed using SAS 9.4 (SAS Institute). Descriptive statistics were calculated for demographic characteristics and baseline clinical variables. Propensity score matching resulted in 174 matched pairs. Variables included in the matching were patient age, patient sex, preoperative left ventricular ejection fraction, history of bicuspid aortic valve, history of connective tissue disease, emergent status of operation, need for concomitant total arch replacement, need for concomitant mitral valve procedure, and need for concomitant coronary artery bypass grafting. Matching was 1:1 using the greedy nearest-neighbor matching method with a caliper of 0.10. Matching was assessed by value and plot of the standardized difference, which are included in Tables E1 and E2 and Figure E1. Analyses were performed between matched and prematched cohorts. For preoperative, intraoperative, and postoperative comparisons, a *t* test (or Mann–Whitney test *U*, as appropriate) was used to compare continuous variables, and χ^2 test (or Monte Carlo exact tests, as appropriate) was used to compare categorical variables. For the matched cohort, paired *t* test or McNemar test was used to compare continuous variables as appropriate. Inferential statistics were performed, including Kaplan–Meier curves for survival probabilities. We determined the hazard ratios with robust sandwich-type variance estimator for the matched groups to account for clustering in matched pairs. As for reoperation, we used a cause-specific hazard model adjusting for death as a competing risk. We performed an independent risk factor analysis to assess risk factors for early and late mortality using univariate and multivariate analysis. Variables included in the risk factor analysis include all demographic variables in Table 1. Risk factors are presented with associated hazard ratio and 95% confidence interval (CI).

RESULTS

Patient Demographics and Preoperative Characteristics

Patients who underwent True-Redo operations were significantly younger, with mean age 49.9 ± 15.1 years versus 55.3 ± 14.7 years, $P < .001$. True-Redo patients were also found to have greater prevalence of concomitant cerebrovascular disease (43, 23.4%), despite lower body mass index (26.3; interquartile range [IQR], 23.9, 30.2), hypertension (122, 66.3%), and dyslipidemia (89, 49.7%), all $P \leq .05$ (Table 1). Preoperative differences were resolved under propensity matching except for persistently greater body mass indexes and greater prevalence of diabetes in the Any-Redo group ($P < .05$). Endocarditis was an indication for surgery in 29.9% (55) of patients in the True-Root group compared with Any-Root at 16% (102), $P < .001$. This difference also did not resolve with matching, $P < .0001$.

The pre-matched True-Redo cohort had lower rates of bicuspid aortic valves (7, 3.8%) compared with Any-Redo (70, 11%), $P < .001$, which resolved after matching. In addition, both matched and pre-matched patients in the True-Redo group had a greater incidence of previous aortic valve, ascending aorta, and aortic arch surgery (100%, 28.8%, 17.9%, respectively, all $P < .001$; Table 1).

TABLE 1. Pre-matched and matched preoperative demographics and previous operations

Preoperative variable	Prematched			Matched		
	True-Redo N = 184	Any-Redo N = 638	*P* value	True-Redo N = 174	Any-Redo N = 174	*P* value
Age, y	49.9 ± 15.1	55.3 ± 14.7	<.01	50.4 ± 15.1	51.6 ± 15.6	.23
Male	147 (79.9)	471 (73.8)	.09	139 (79.9)	143 (82.2)	.58
BMI	26.3 (23.9, 30.2)	27.7 (24.2, 31.9)	<.01	26.4 (23.9, 30.3)	28.1 (24.2, 32.2)	.72
Comorbidities						
Diabetes	20 (10.9)	98 (15.4)	.13	19 (11.0)	33 (19.0)	.04
Hypertension	122 (66.3)	488 (76.5)	.01	114 (65.5)	124 (71.3)	.20
Dyslipidemia	89 (49.7)	369 (59.6)	.02	84 (49.7)	96 (57.5)	.07
CVD	43 (23.4)	109 (17.1)	.05	41 (23.6)	32 (18.5)	.23
Dialysis	4 (2.2)	15 (2.4)	1	4 (2.3)	7 (4.0)	.37
PAD	14 (7.6)	70 (11.0)	.18	14 (8.0)	19 (10.9)	.37
Arrhythmia	48 (31.8)	149 (29.8)	.64	47 (32.9)	46 (32.6)	.89
CTD	10 (5.4)	21 (3.3)	.18	8 (4.6)	8 (4.6)	1
Emergent/urgent	98 (53.3)	327 (51.3)	.63	90 (51.7)	94 (54.0)	.66
LVEF	55.0 (48.0, 60.0)	55.0 (50.0, 60.0)	1	55.0 (48.0, 60.0)	55.0 (48.0, 60.0)	.41
2+ aortic insufficiency	76 (53.5)	252 (49.9)	.45	73 (53.3)	69 (48.9)	.81
BAV	7 (3.8)	70 (11.0)	<.01	7 (4.0)	7 (4.0)	1
Endocarditis	55 (29.9)	102 (16.0)	<.01	54 (31.0)	25 (14.4)	<.01
Previous interventions						
Previous ascending	53 (28.8)	121 (19.0)	<.01	51 (29.3)	32 (18.4)	.02
Previous Arch	33 (17.9)	25 (3.9)	<.01	32 (18.4)	2 (1.1)	<.01
Previous AV intervention	184 (100.0)	393 (61.6)	<.01	174 (100.0)	106 (60.9)	<.01
Previous CABG	20 (10.9)	94 (14.7)	.18	19 (10.9)	29 (16.7)	.11
Previous MV intervention	3 (1.6)	25 (3.9)	.13	3 (1.7)	7 (4.0)	.21
Other	5 (2.7)	29 (4.5)	.27	5 (2.9)	5 (2.9)	1

Continuous variables given as mean ± standard deviation or median (interquartile range) as appropriate and categorical variables presented as count (% of cohort). *BMI*, Body mass index; *CVD*, cerebrovascular disease; *PAD*, peripheral arterial disease; *CTD*, connective tissue disease; *LVEF*, left ventricular ejection fraction; *BAV*, bicuspid aortic valve; *AV*, aortic valve; *CABG*, coronary artery bypass grafting; *MV*, mitral valve.

Operative Techniques and Findings

Patients in the True-Redo group required longer cardiopulmonary bypass (251 minutes; IQR, 201, 301 minutes), $P < .0001$, and aortic crossclamp times (196 minutes; IQR, 157, 242 minutes), $P = .03$. These differences persisted in the propensity-matched cohorts (Table 2). In addition, in the matched groups, hypothermic circulatory arrest times were also longer in True-Redo (29 minutes; IQR, 21, 44 minutes vs 22 minutes; IQR, 13, 32 minutes), $P = .01$. In the prematched comparison, the incidence of concomitant procedures did not differ significantly between groups except for more zone 2/3 arch replacement among Any-Redo (69, 10.8%), which became insignificant in the matched groups. Need for concomitant coronary artery bypass grafting was 21% and was without significant difference between the 2 groups, $P = .92$. More intra-aortic balloon pumps were needed in True-Redo for both matched and prematched groups, $P < .05$ (Table 2).

Early Outcomes

In-hospital mortality rates in the prematched comparison were 14.7% (27) for True-Redo and 12.4% (79) for Any-Redo, $P = .41$ (Table 3). Incidence of postoperative atrial fibrillation was lower in the True-Redo group (44, 24%, $P = .01$); this difference resolved with matching. In the matched analysis True-Redo (27, 15.5%) had greater rates for bleeding requiring operative intervention, $P = .05$. The lengths of intensive care unit ($P = .28$) and hospital ($P = .36$) stays were without significant difference between groups (Table 3).

Late Clinical Outcomes

There was no significant difference in late 10-year survival rates: 71% versus 68% for the True-Redo and Any-Redo groups, respectively, and late mortality causes are listed in Table E2. These survival curves converge at 6 years' postoperatively (Figure 1). Landmark survival analysis was used to determine inflection point of survival curves and revealed that when analyzing those patients surviving at least 4 years, patients in the True-Redo group carried a survival advantage (Figure 2). This survival advantage persisted in the matched patient analysis, $P = .046$. Cumulative incidence of aortic reoperation, combined event of redo-aortic valve replacement, redo-ROOT, and ascending aorta

TABLE 2. Operative data including cardiopulmonary bypass, aortic crossclamp, and circulatory arrest times as well as concomitant operations

Procedural variable	Prematched			Matched		
	True-Redo N = 184	Any-Redo N = 638	*P* value	True-Redo N = 174	Any-Redo N = 174	*P* value
ROOT operation performed						
VSRR	16 (8.7)	71 (11.1)	.34	15 (8.6)	19 (10.9)	.45
Aortic valve repair	4 (2.2)	20 (3.1)	.5	4 (2.3)	6 (3.4)	.53
Mechanical valve	46 (25.0)	123 (19.3)	.09	42 (24.1)	36 (20.7)	.43
Bioprosthetic valve	118 (64.1)	417 (65.4)	.76	113 (64.9)	110 (63.2)	.71
Concomitant operation						
Ascending replacement	125 (67.9)	443 (69.4)	.97	119 (68.4)	112 (64.4)	.61
+ Hemiarch replacement	65 (35.3)	198 (31.0)	.27	64 (36.8)	64 (36.8)	1
+ Zone 2 or 3 arch	9 (4.9)	69 (10.8)	.02	6 (3.4)	3 (1.7)	.08
Mitral valve procedure	11 (6.0)	59 (9.2)	.16	11 (6.3)	12 (6.9)	.82
CPB time, min	251.0 (201.0, 300.5)	220.0 (181.0, 276.0)	<.01	251.5 (199.0, 305.0)	220.0 (183.0, 263.0)	<.01
AXC time, min	196.0 (157.0, 242.0)	183.0 (141.0, 220.0)	.03	199.3 ± 64.1	180.6 ± 58.3	<.01
Circ. arrest time, min	29.0 (20.5, 45.5)	25.0 (17.0, 43.0)	.09	29.0 (21.0, 44.0)	22.0 (13.0, 32.0)	.11
Intraoperative IABP	51 (27.7)	110 (17.2)	<.01	48 (27.6)	30 (17.2)	.02

Continuous variables given as mean ± standard deviation or median (interquartile range) as appropriate and categorical variables presented as count (% of cohort). *ROOT*, Aortic root replacement; *VSRR*, valve-sparing root replacement; *CPB*, cardiopulmonary bypass time; *AXC*, aortic crossclamp time; *IABP*, intra-aortic balloon pump.

replacement, was 9% for the True-Redo group and 10% for the Any-Redo group, $P = .39$ (Figure 3).

Multivariate Risk Factor Analysis

Risk factors for early mortality include increased patient age ($P < .0001$, relative risk [RR], 1.04; 95% CI, 1.03-1.06) and male sex ($P = .003$, RR, 1.95; 95% CI, 1.36-2.79). Increased preoperative left ventricular ejection fraction was protective of early mortality ($P = .021$, RR, 0.98; 95% CI, 0.97-0.997). The risk factors found for long-term mortality included age, male sex, preoperative renal failure, peripheral artery disease, preoperative left ventricular ejection fraction, emergent status of the redo surgery, as well as previous ascending aortic surgery, aortic valve replacement, and coronary artery bypass grafting, all $P < .05$ (Table 4).

COMMENT

This multi-institutional study retrospectively reviewed and compared outcomes of patients who underwent ROOT after any previous sternotomy (Any-Redo) versus those who underwent ROOT after a previous ROOT (True-Redo). The study comprised 822 patients over a 17-year period from 2004 to 2021 with the primary end point of mortality and secondary end point of reoperation. The 184 patients in the True-Redo-ROOT group comprise the largest such reported series to date. Early mortality and late mortality did not differ between the groups. However, among the total cohort surviving at least 4 years, patients in the True-Redo-ROOT had improved survival compared with patients in the Any-Redo-Root group, with an incidence of reoperation without significant difference. Risk factor analysis revealed that older patients and those with

TABLE 3. Early postoperative outcomes of the unmatched and matched cohorts

Outcome	Prematched			Matched		
	True-Redo N = 184	Any-Redo N = 638	*P* value	True-Redo N = 174	Any-Redo N = 174	*P* value
Mortality	27 (14.7)	79 (12.4)	.41	25 (14.4)	26 (14.9)	.88
Stroke	11 (6.0)	24 (3.8)	.19	11 (6.3)	5 (2.9)	.13
ESRD	26 (14.1)	86 (13.5)	.82	25 (14.4)	23 (13.2)	.76
Respiratory failure	66 (35.9)	224 (35.1)	.85	62 (35.6)	64 (36.8)	.83
Bleeding	28 (15.2)	74 (11.6)	.19	27 (15.5)	15 (8.6)	.05
Atrial fibrillation	44 (23.9)	213 (33.4)	.01	43 (24.7)	49 (28.2)	.47
Pacemaker	14 (7.6)	58 (9.1)	.53	13 (7.5)	15 (8.6)	.71
ICU LOS, h	74.9 (40.3, 181.5)	88.8 (43.6, 161.8)	.28	75.9 (40.5, 174.3)	85.9 (42.5, 161.7)	.39
Hospital LOS, d	11.0 (7.0, 20.5)	10.0 (7.0, 17.0)	.36	11.0 (7.0, 20.0)	11.0 (7.0, 17.0)	.18

Continuous variables given as mean ± standard deviation or median (interquartile range) as appropriate and categorical variables presented as count (% of cohort). *ESRD*, End-stage renal disease; *ICU*, intensive care unit; *LOS*, length of stay.

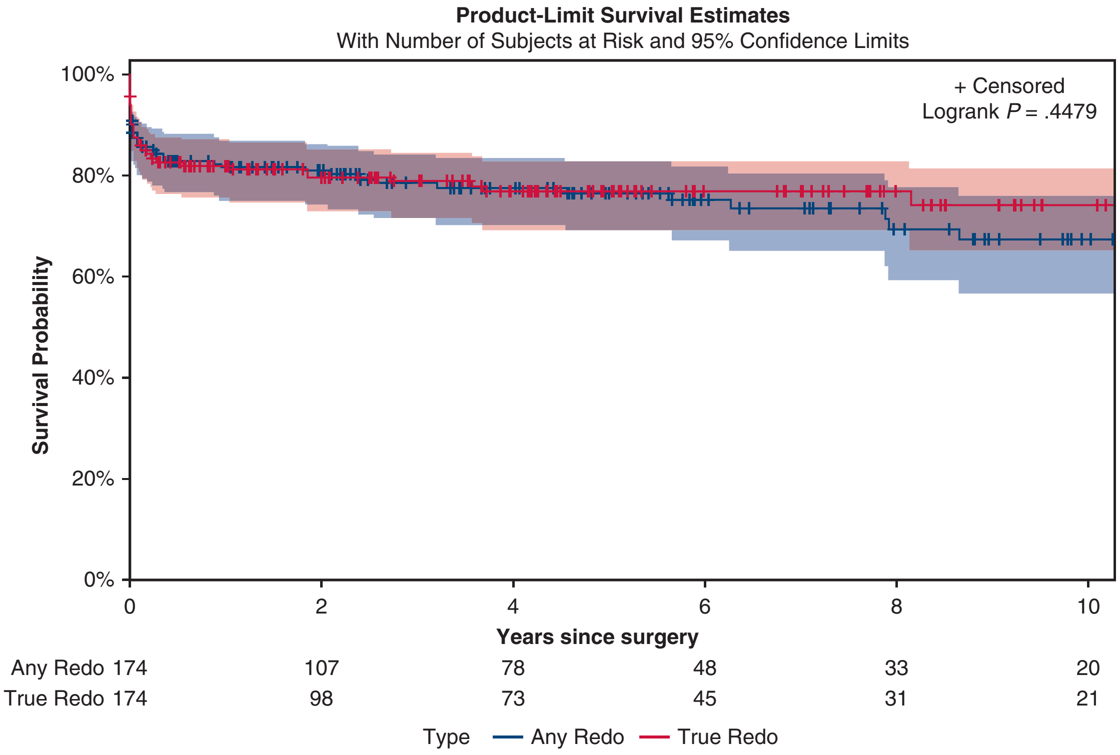

FIGURE 1. Kaplan–Meier survival analysis comparing matched True-Redo-ROOT versus Any-Redo-ROOT with the number at risk listed below the figure and 95% confidence interval shown with *shading*. Log-rank comparison revealed $P = .45$.

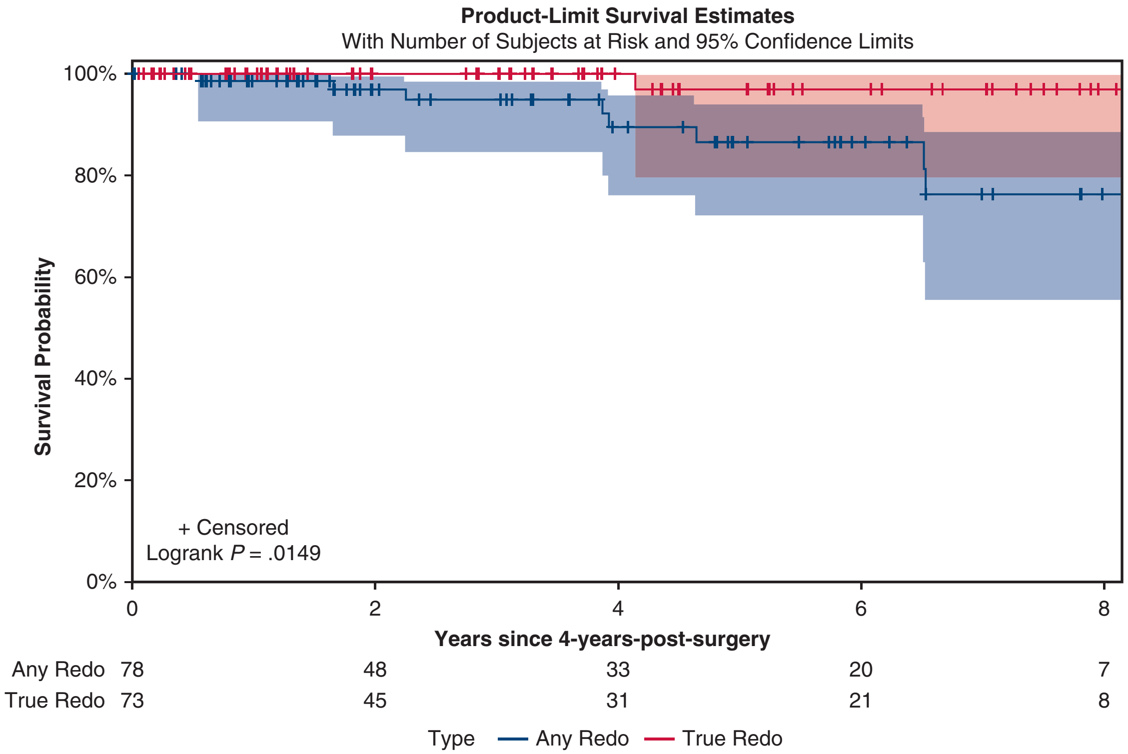

FIGURE 2. Landmark survival analysis setting time = 0 to 4 years postoperative of the matched cohorts. Log rank comparison $P = .025$. Number at risk listed at the below the graph and 95% confidence interval shown with *shading*.

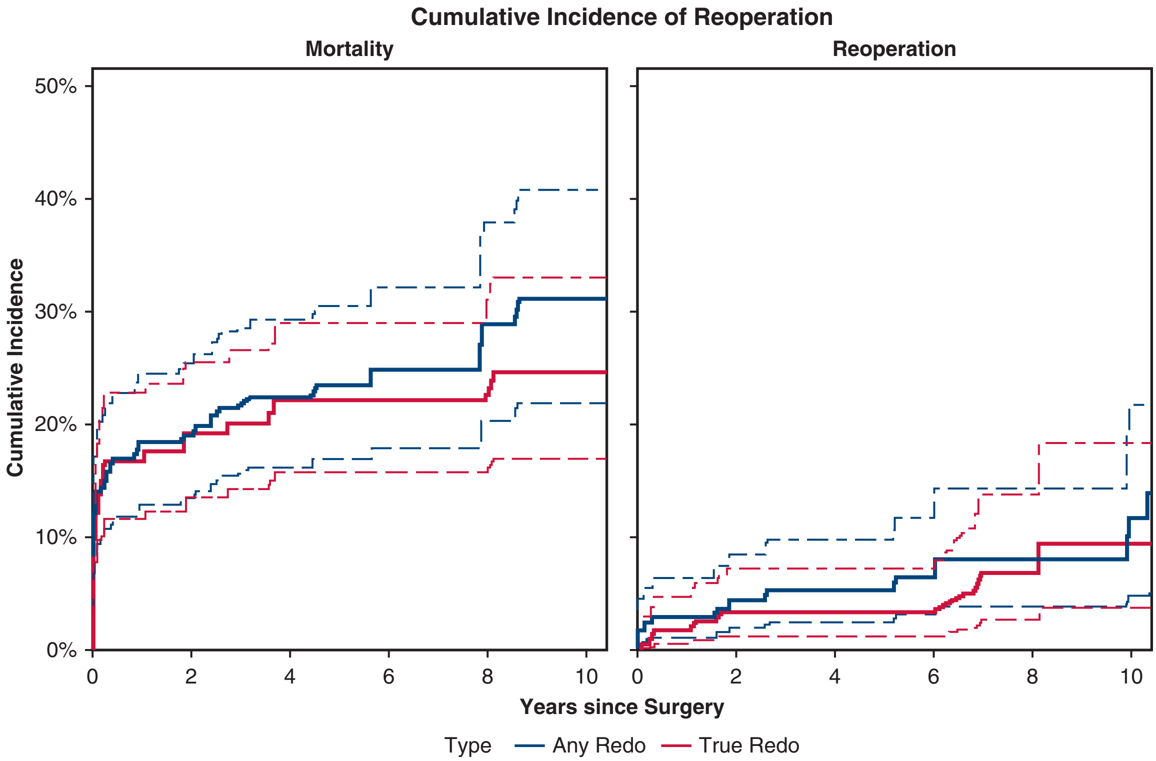

FIGURE 3. Competing risk analysis of the cumulative incidence of reoperation versus mortality for the matched Any-Redo and True-Redo cohorts, $P = .35$. Number at risk listed at the below the graph and 95% confidence interval shown with *dashed lines*.

reduced left ventricular ejection fraction are at risk for early mortality.

Operative mortality after ROOT, based on a study reporting data from the Society of Thoracic Surgeons Database, is 4.2%.[1] In that analysis, redo-sternotomy ROOT carried a greater mortality at 8.9% versus primary sternotomy ROOT at 3.5%.[1] Although more recent single-center series have found operative mortality after redo-sternotomy ROOT as high as 14% to 18%, it was 13% in the present study.[12,13] The increased risk of aortic root surgery in the setting of redo-sternotomy has been attributed to a multitude of factors, including, but not limited to, re-entry injury, suboptimal surgical timing with or without increased comorbid conditions, and increased need for concomitant operations.[8,12,14]

Bioprosthetic valves are being implanted in younger patients during surgical aortic valve replacement, and transcatheter aortic valve replacement is being trialed in low-risk and younger patients.[15,16] Although the long-term data of the latter is pending, current data regarding the use of surgical bioprostheses in younger patients indicate that there may be an increased need for reoperative aortic valve surgery in the future.[17] Many of these patients, regardless of the clinical indication, will need full ROOT.[18,19] In fact, 61% of the Any-Redo group in this study had previous aortic valve surgery. The Any-Redo group in this study should serve as a benchmark for outcomes after redo-sternotomy root replacement for these patients.

Limited data exist regarding full ROOT after previous ROOT (True-Redo-ROOT). The 4 most recent studies

TABLE 4. Risk factors for long-term mortality

Variable	HR	95% confidence interval		*P* value
Older age	1.035	1.023	1.047	<.0001
Preoperative ESRD	2.588	1.294	5.177	.0072
Preoperative PAD	1.861	1.219	2.842	.004
Emergent case	1.856	1.357	2.54	.0001
Previous ascending	1.965	1.393	2.773	.0001
Previous CABG	1.667	1.131	2.456	.0098

HR, Hazard ratio; *ESRD*, end-stage renal disease; *PAD*, peripheral artery disease; *CABG*, coronary artery bypass grafting.

addressing this issue had early morality ranging from 2.4% to 10%, with series size ranging from 69 to 120 patients.[10,11,14,20] Ultimately mid-term survival was without significant difference between this and the other contemporary series.[10,11,14,20] Five-year survival was 72% to 89% and 10-year survival 73% to 81% in these single-center series.[10,11,14,20]

The current 184-patient series is the largest to date and has a slightly greater early mortality at 15% and with a 10-year survival without significant difference compared to other studies. Of note, 53% of the operations in the current series were performed either urgently or emergently and 40% required concomitant arch intervention. These data confirm a greater complexity of the current study cohort than other comparable series and likely contributed to a longer mean cardiopulmonary bypass time at 251 minutes versus 140 to 220 minutes.[10,11,14,20] The greater prevalence of arch intervention and longer cardiopulmonary bypass time likely contributed to the greater early mortality.

Comparison of Any-Redo-ROOT versus True-Redo-ROOT was the primary focus of this study. With this comparison, the goal was to isolate the impact of previous root replacement on aortic root surgery. The presence of aortic root adhesions from previous coronary reimplantation increases the complexity of reoperative root dissection and the risk of injury to the coronary arteries and other adjacent cardiac structures.[14] These adhesions and potential prosthetic root calcification can also make coronary mobilization more difficult.[11] Adequate coronary mobilization in the True-Redo-ROOT setting is critical to achieving a torsion- and tension-free coronary anastomosis and is essential for a good outcome. Brown and colleagues[14] performed a similar matched analysis, with 66 patients in each group, and concluded that "True-Redo" status does not impact outcomes. Similarly, this study did not find that "True-Redo" to negatively impacts outcomes when compared with "Any-Redo." In those patients surviving beyond 4 years, it is not completely clear, based on the results of this study, why the patients in the True-Redo group had a survival advantage compared with the Any-Redo group. One potential explanation is that patients in the "Any-Redo" group may have had a greater variety of "nonaortic valve/root" pathology in addition to aortic root pathology and that this multiplicity of problems adversely affected those patients' survival.

Although other studies have found endocarditis to be a risk factor for mortality, it was not the case in the present study.[10] In fact, despite a greater rate of endocarditis in the True-Redo-ROOT group, our landmark survival analysis showed that of those patients surviving at least 4 years, the patients in the True-Redo-ROOT group had improved subsequent survival. Aggressive removal of any infection, even in the face of more extensive concomitant operations, is critical to success with this particular patient population.

Limitations

Limitations of this study include its retrospective nature. The study groups were, as expected, disparate with regards to their age and incidence of endocarditis. Propensity scoring allowed for presentation of adjusted outcomes. In addition, this series took place at 2 high-volume centers, and our findings may not be generalizable to lower-volume centers. Lastly, the completeness of follow-up for this patient population is particularly difficult, and this is recognized as a limitation to this study. Similarly echocardiographic follow-up is not as optimal as desired and is in the process of being collected.

CONCLUSIONS

This study presents the largest series to date of True-Redo-ROOT replacement and compares outcomes to patients undergoing ROOT after previous sternotomy for any previous cardiac surgery. Both true-redo-ROOT and any-redo-ROOT can be performed safely with acceptable clinical outcomes. Despite longer cardiopulmonary bypass and aortic crossclamp times, early mortality between the 2 groups was largely without significant difference and consistent with other recent similar studies. Overall survival and rate of reoperation was also without significant difference between the 2 groups and corroborated contemporary series. However, the landmark analysis findings of improved survival for the True-Redo group for those patients surviving at least 4 years is unique to this study. Similar to other studies, certain patient populations are at greater risk for early and late mortality. The decision to perform a redo-ROOT should be taken seriously and must be individualized in a patient-specific manner for optimal outcomes.

Conflict of Interest Statement

The authors reported no conflicts of interest.

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

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Key Words: aortic root replacement, aortic valve, aortic surgery, reoperation

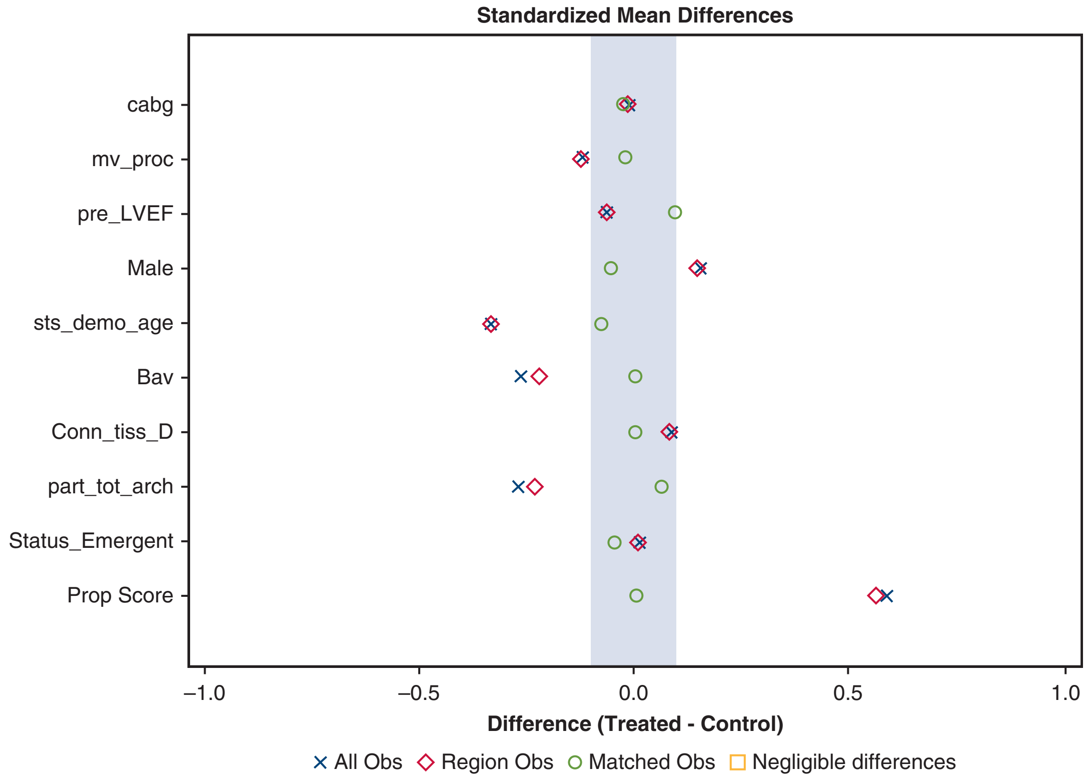

FIGURE E1. Plot of standardized differences in variables pre and post matching. *CABG*, Concomitant coronary artery bypass grafting; *mv_proc*, concomitant mitral valve surgery, *pre-LVEF*, preoperative left ventricular ejection fraction; *sts_demo_age*, age at operation; *BAV*, history of bicuspid aortic valve; *Conn_tiss_D*, history of connective tissue disorder, *part_total_arch*, concomitant arch intervention; *Prop Score*, propensity score; *obs*, observations.

TABLE E1. Standardized differences after matching

Variable	Mean difference	Standardized difference	Percent reduction	Variance ratio
Age	−1.14368	−0.07629	76.97	0.9345
Sex	−0.02299	−0.05418	63.69	1.0975
Emergent status	−0.02299	−0.04591	0	1.0053
Connective tissue disease	0	0	100	1
Bicuspid aortic valve	0	0	100	1
Preoperative LV ejection fraction	0.96839	0.09412	0	0.6261
Total arch replacement	0.01724	0.06593	75.58	1.9649
Mitral valve surgery	−0.00575	−0.02129	82.73	0.9223
Coronary artery bypass surgery	−0.01149	−0.02855	0	0.9598

LV, Left ventricular.

TABLE E2. Overall causes of late mortality for the total cohort

Cause of death	N (%)
Unknown	25 (29%)
Cardiac arrest	13 (15%)
Heart failure	10 (11%)
Early mortality after reoperation	2 (2%)
Endocarditis	4 (5%)
Coronary artery disease	2 (2%)
Stroke/seizure	7 (8%)
COPD	6 (7%)
Pneumonia	2 (2%)
Sepsis	6 (7%)
Cancer	2 (2%)
Multiple organ failure	5 (6%)
Other	3 (3%)

Categorical variables presented as count (% of cohort). *COPD*, Chronic obstructive pulmonary disease.