Redo aortic surgery: Does one versus multiple affect outcomes?

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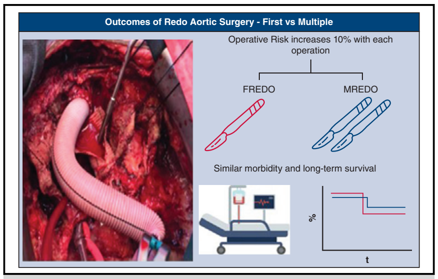
ABSTRACT

Objective: Redo aortic surgery has a higher risk of morbidity and mortality because it is technically complex due to mediastinal adhesions, infection, and previously implanted prostheses. In this study, we sought to benchmark our single-center experience comparing outcomes in patients undergoing aortic surgery after 1 versus multiple previous cardiac operations.

Methods: Between 2004 and 2019, 429 patients underwent redo aortic surgery. They were classified as aortic surgery after 1 previous surgery (first redo surgery, n = 360) and aortic surgery after 2 or more (multiple) previous surgeries (multiple redo surgery, n = 69). Postoperative outcomes and long-term survival were compared, and risk factors for mortality were identified.

Results: Thirty-day mortality was lower in first redo surgery compared with multiple redo surgery (12.3% vs 21.7%, *P* = .03). Age, cardiopulmonary bypass time, intra-aortic balloon pump use, postoperative cerebrovascular accident, absence of postoperative atrial fibrillation, intra-aortic balloon pump, and multiple redo surgery were independent predictors of 30-day mortality. Long-term survival was similar at 15 years. Patients who received first redo surgery were older (57.9 ± 14.0 years vs 50.3 ± 15.8 years, *P* = .0001) and had a higher incidence of hypertension (84.7% vs 73.9%, *P* = .02), whereas patients who received multiple redo surgery had a higher incidence of cerebrovascular disease (31.9% vs 20.3%, *P* = .03). Aortic valve replacement was the most common previous operation with higher incidence in multiple redo surgery. Incidence of previous aortic surgery was similar. Cardiopulmonary bypass (246 ± 67.3 minutes vs 219.9 ± 57.5 minutes, *P* = .009) and crossclamp times (208.2 ± 51.8 vs 181.9 ± 50.8 minutes, *P* = .004) were longer in multiple redo surgery. Incidence of reentry injury and balloon pump insertion were similar. Extracorporeal membrane oxygenation use was higher in multiple redo surgery. Postoperative complications occurred at similar rates, except for higher incidence of dialysis in multiple redo surgery (14.5% vs 7.2%, *P* = .04).

Conclusions: Multiple redo aortic procedures have a higher morbidity and mortality compared with first redo aortic procedures, with linearly increasing short-term mortality risk but similar long-term survival with the number of redo procedures. (JTCVS Open 2023;16:158-66)



Comparison of outcomes with FREDO versus MREDO aortic surgery.

CENTRAL MESSAGE

Redo aortic surgery is technically challenging and becomes more complex with higher operative risk with increasing number of previous cardiac operations.

PERSPECTIVE

Redo aortic surgery can be performed with a 12% to 21% risk of mortality in a high-volume center of expertise. Higher number of previous cardiac operations increases operative risk and 30-day mortality. However, postoperative morbidity and long-term survival remain similar. Careful preoperative planning and alternate cannulation strategies are essential for successful outcomes.

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Institutional Review Board Approval: IRB00022795, date: August 3, 2009.

Read at The American Association for Thoracic Surgery Aortic Symposium, Boston, Massachusetts, May 13-14, 2021.

Received for publication May 17, 2023; revisions received Aug 29, 2023; accepted for publication Sept 21, 2023; available ahead of print Oct 30, 2023.

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2666-2736

https://doi.org/10.1016/j.xjon.2023.09.035

Abbreviations and Acronyms

AVR	= aortic valve replacement
CABG	= coronary artery bypass grafting
CPB	= cardiopulmonary bypass
CT	= computed tomography
FREDO	= first redo surgery (aortic surgery after 1 previous surgery)
IABP	= intra-aortic balloon pump
MREDO	= multiple redo surgery (aortic surgery after ≥2 previous surgeries)
NHYA	= New York Heart Association

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Redo aortic operations are being performed with increased frequency in the United States,[1,2] either from complications of an earlier index procedure from aneurysmal degeneration of adjacent aortic segments of the aorta, prosthetic aortic valve degeneration, graft infection, or pseudoaneurysm formation. Irrespective of the etiology, aortic surgery performed in a reoperative setting is complex and may be associated with significant morbidity and mortality. Some of the factors contributing to this risk are mediastinal adhesions with potential reentry injury, the presence of infection, increased risk of bleeding from tissue friability, previous coronary grafts, and risk of conduction abnormalities in recovering previously implanted prostheses. The probability of this surgical risk increasing in these complex operations based on the number of previous operations is likely higher, because the severity of the various contributing factors is exacerbated. Therefore, in the current quality metrics-driven reimbursement environment with newer minimally invasive options on the horizon, establishing benchmarking data and expectations for these difficult clinical scenarios is critically important.

Overall, morbidity and mortality associated with redo proximal aortic surgery is significant, with a reported operative mortality risk of 11% to 15% in the literature.[3-7] However, data focused on outcomes after multiple previous cardiac operations are still limited. A study by Dossche and colleagues[8] identified 2 or more previous operations as a univariate risk factor for mortality, but data comparing differences in outcomes of first-time redo versus multiple redo operations are virtually unknown. In this study, we specifically sought to investigate the differential impact of first versus multiple thereafter cardiac operations on short- and long-term outcomes of patients undergoing redo aortic surgery.

PATIENTS AND METHODS

Patient Inclusion

The Society of Thoracic Surgeons database and electronic medical records of patients at our institution who underwent redo aortic surgery between March 2004 and February 2019 were queried. Institutional Review Board approval was obtained for the study (IRB00022795, date: August 3, 2009), and the need for individual patient consent was waived. Their inpatient records and operative notes were examined to determine their inclusion in the study. Inclusion criteria into the study were elective or urgent aortic valve ascending aortic surgery in the presence of a previous sternotomy. Patients with descending aortic repair and patients undergoing sternotomy after a previous endovascular procedure were excluded. A total of 442 patients were identified, and 13 patients who underwent redo thoracotomies for descending aortic surgery were excluded. The remaining 429 patients were then divided into first redo surgery (FREDO, n = 360) and multiple redo surgery (MREDO, third or more sternotomy, n = 69) groups. Patient demographics, operative details and postoperative outcomes were compared.

Indications for Surgery

Operations were performed primarily for aortic pathology including aneurysmal disease as well as dissection and valvular degeneration, encompassing both native and prosthetic dysfunction or a combination thereof. Concomitant procedures including coronary artery bypass grafting (CABG) and other valvular operations were also performed as part of the index aortic procedure. The choice of valvular prosthesis was determined by the surgeon in conjunction with patient preferences.

Preparation for Redo Sternotomy

Computed tomography (CT) scan imaging was critical in preparation for surgery not only for assessment of aortic pathology but also for assessment of cardiac structures in relation to the posterior table of the sternum. Other imaging studies included a cardiac catheterization and transthoracic or transesophageal echocardiography. Axillary artery and bilateral groin areas were routinely prepped, and one of them was opened on a selective basis depending on the estimated degree of likelihood for cardiac injury upon sternal reentry. In general, femoral-femoral or axillary-femoral bypass cannulation was not routinely performed before chest reentry, except for a few cases where the aorta was densely adhered to posterior table of the sternum.

Surgical Conduct

Sternal reentry was performed with an oscillating saw. Circulation management for proximal aortic arch reconstruction was performed with hypothermic circulatory arrest using antegrade or retrograde cerebral perfusion, which was dependent on anatomic considerations and surgeon preference. Our technique of circulation management has been described as well as our conduct of redo-aortic procedures.[3,9] In cases of reentry injury, expeditious peripheral cannulation and temporary sternal closure were performed to tamponade the bleeding while cooling the patient to safely allow for a brief period of circulatory arrest to complete the reentry process. Upon reentry, tissue dissection was carried out only in areas needed to safely conduct the designated operation.

In general, a normally functioning mechanical or bioprosthetic valve was not replaced. The indications to remove a well-functioning mechanical valve included coumadin intolerance due to severe bleeding complications and patient preference of switching to a bioprosthetic valve.

Redo thoracotomies to repair thoracoabdominal aneurysms were done in 12 patients and were more common in the MREDO group, in which case they had multiple previous sternotomies or a sternotomy and thoracotomy. These patients were excluded from the analysis.

Patient Follow-up

Postoperative outpatient follow-up consisted of patient visits at 6 weeks, 6 months, and then annually thereafter. Imaging surveillance was performed at 6 months and 1 year after which they were surveilled annually. Mortality data were obtained from patient records or Legacy.com (an online obituary reporting forum).

Statistical Analysis

FREDO and MREDO were compared using the 2-sample *t* test (or Mann–Whitney *U* test when necessary) for continuous variables and the chi-square test (or Fisher exact test when necessary) for dichotomous variables. Univariable and multivariable logistic regression analyses were performed to identify risk factors predicting 30-day mortality and longer length of stay. In the final model, a Poisson regression model with a robust error variance was fit to obtain point estimates of risk ratios and CIs. For long-term mortality, Kaplan–Meier survival curves were plotted, and the log-rank test was used to compare the survival experience of FREDO and MREDO. All tests of hypotheses were 2-sided and conducted at .05 level of significance. SAS 9.4 was used to perform all statistical analyses.

RESULTS

Preoperative Characteristics

Mean patient age of the entire cohort was 56.7 ± 14.6 years, and 304 (70.9%) were men. Table 1 outlines the baseline demographic and preoperative characteristics of the 2 groups. Patients in the FREDO group were older than in the MREDO group (57.9 ± 14.0 years vs 50.3 ± 15.8 years, $P = .0001$) and had a higher incidence of hypertension (84.7% vs 73.9%, $P = .02$). Incidence of cerebrovascular disease was higher in the MREDO group compared with the FREDO group (31.9% vs 20.3%, $P = .03$). Median ejection fractions and NYHA class heart failure incidences were similar between the groups. The remainder of the preoperative characteristics were similar between groups.

Previous Cardiac Surgical History

As shown in Table 2, aortic valve replacement (AVR) was the most common previous cardiac operation (n = 261, 60.8%) and was more common in the MREDO group at 78.3% versus 57.5% in the FREDO group ($P = .001$). A total of 174 patients (40.6%) had previous aortic surgery and 93 patients (21.7%) had previous CABG, which trended toward a higher incidence in the FREDO group.

Indications for the Redo Surgery

The majority of patients (56.6%) underwent a redo operation for aneurysmal degeneration of the aortic root, ascending aorta, or arch. Other indications for the operation were valvular dysfunction, patient prosthesis mismatch, paravalvular leaks, pseudoaneurysm of ascending aorta, endocarditis/graft infection, and type A dissection as listed in Table 1. All type A dissections encountered in this cohort

TABLE 1. Demographic and preoperative characteristics

Characteristics	Entire sample (n = 429)	FREDO (n = 360)	MREDO (n = 69)	*P* value
Age (y) mean ± SD	56.7 ± 14.6	57.9 ± 14.0	50.3 ± 15.8	<.0001
Male, n (%)	304 (70.9)	259 (71.9)	45 (65.2)	.26
Preoperative diagnoses				
Cerebrovascular disease, n (%)	95 (22.1)	73 (20.3)	22 (31.9)	.03
Chronic lung disease, n (%)	49 (11.4)	39 (10.9)	10 (14.5)	.45
Diabetes, n (%)	66 (15.4)	60 (16.7)	6 (8.8)	.10
Dyslipidemia, n (%)	255 (59.4)	220 (61.1)	35 (50.7)	.10
Hypertension, n (%)	356 (83.0)	305 (84.7)	51 (73.9)	.02
Renal failure dialysis, n (%)	6 (1.4)	5 (1.4)	1 (1.5)	>.99
Prior MI, n (%)	53 (12.4)	44 (12.2)	9 (13.0)	.84
Ejection fraction, median (Q1-Q3)	55.0 (50.0-60.0)	55.0 (50.0-60.0)	58.0 (50.0-60.0)	.07
Smoking n (%)	171 (39.9)	162 (45.0)	9 (13.0)	0
NYHA class I-II, n (%)	127 (29.6)	108 (30.0)	19 (27.5)	.68
NYHA Class III-IV, n (%)	147 (34.3)	118 (32.8)	29 (42.0)	.13
Indications for operation				
Valve dysfunction, n (%)	193 (44.9)	156 (43.3)	37 (53.6)	.03
Paravalvular leak, n (%)	4 (0.9)	2 (0.5)	2 (2.8)	.13
Pseudoaneurysm of ascending aorta, n (%)	31 (7.2)	25 (6.9)	6 (8.6)	.31
Aneurysmal degeneration of root, ascending aorta or arch, n (%)	239 (55.7)	216 (60)	23 (33.3)	.0001
Endocarditis/graft infection, n (%)	49 (11.4)	38 (10.5)	11 (15.9)	.12
Type A dissection, n (%)	8 (1.8)	7 (1.9)	1 (1.4)	.38

FREDO, First redo surgery; *MREDO,* multiple redo surgery; *SD,* standard deviation; *MI,* myocardial infarction; *NYHA,* New York Heart Association.

TABLE 2. Previous cardiac surgical characteristics

Previous surgeries	Entire sample (n = 429)	FREDO (n = 360)	MREDO (n = 69)	*P* value
CABG	93 (21.7%)	84 (23.3%)	9 (13.0%)	.057
Aortic surgery	174 (40.6%)	149 (41.4%)	25 (36.2%)	.42
AVR	261 (60.8%)	207 (57.5%)	54 (78.3%)	.001
Other	132 (30.8%)	113 (31.4%)	19 (27.5%)	.52
Time between current and previous surgery in years, median (Q1-Q3)	9.4 (4.5-14.9)	9.6 (4.9-14.9)	7.8 (2.9-13.5)	.20

FREDO, First redo surgery; *MREDO,* multiple redo surgery; *CABG,* coronary artery bypass grafting; *AVR,* aortic valve replacement.

were after previous CABG or AVR. No operations were for an acute dissection after prior proximal aortic repair.

Operative Characteristics

Table 3 compares the operative characteristics between the 2 groups. The majority of operations were redo sternotomies (97%). The most common operation performed was aortic root replacement and was also more commonly done in the MREDO group (75% vs 60.1%, $P = .03$). For valve replacement, a bioprosthetic valve was more commonly used (78.4% of all valve replacements), but mechanical valve use was higher in the MREDO group (25.7% vs 10.3%, $P = .0003$). Concomitant CABG, either planned or emergency, was performed in 89 patients (20%).

Cardiopulmonary bypass (CPB) times (FREDO: 219.9 ± 57.5 minutes vs MREDO: 246.0 ± 67.3 minutes, $P = .0009$) and crossclamp times (FREDO: 181.9 ± 50.8 minutes vs MREDO: 208.1 ± 51.8 minutes, $P = .0004$) were significantly longer in the MREDO group. We used circulatory arrest in 251 patients (58%) and antegrade cerebral perfusion via axillary artery cannulation in the majority of the patients (232/251). These were used with similar

TABLE 3. Operative characteristics

Surgical procedures	Entire sample (n = 429)	FREDO (n = 360)	MREDO (n = 69)	*P* value
Aortic valve repair, n (%)	14 (3.3)	12 (3.3)	2 (2.9)	>.99
Mechanical valve, n (%)	56 (13.1)	37 (10.3)	19 (27.5)	.0001
Bioprosthetic valve, n (%)	206 (48.1)	176 (49)	30 (43.5)	.39
Ascending replacement, n (%)	255 (59.4)	212 (58.9)	43 (62.3)	.59
Aortic root replacement, n (%)	277 (64.6)	221 (61.4)	56 (81.2)	.001
Hemi-arch replacement, n (%)	176 (41)	141 (39.2)	35 (50.7)	.07
Zone 2 arch replacement, n (%)	14 (3.3)	12 (3.3)	2 (2.9)	>.99
Total arch replacement, n (%)	27 (6.1)	23 (6.2)	4 (5.4)	.07
Stage I Elephant trunk, n (%)	35 (8.2)	34 (9.4)	1 (1.4)	.02
CABG, n (%)	88 (20.5)	77 (21.4)	11 (15.9)	.22
CPB time (mean ± SD)	224.1 ± 59.9	219.9 ± 57.5	246.0 ± 67.3	.0009
Crossclamp time, (mean ± SD)	185.4 ± 51.7	181.9 ± 50.8	208.1 ± 51.8	.0004
Axillary cannulation, n (%)	260 (60.6)	219 (60.8)	41 (59.4)	.82
Femoral venous cannulation, n (%)	50 (11.7)	39 (10.8)	11 (15.9)	.22
Antegrade cardioplegia, n (%)	246 (57.3)	204 (56.7)	42 (60.9)	.51
Antegrade and retrograde cardioplegia, n (%)	173 (39.9)	145 (40.3)	26 (37.7)	.68
Circulatory arrest, n (%)	251 (58.6)	211 (58.8)	40 (58.0)	.90
Antegrade cerebral perfusion, n (%)	232 (54.1)	199 (55.3)	33 (47.8)	.25
Retrograde cerebral perfusion, n (%)	19 (4.4)	16 (4.4)	3 (4.3)	>.99
IABP, n (%)	108 (25.2)	86 (23.9)	22 (31.9)	.16
ECMO, n (%)	2 (0.5)	0 (0.0)	2 (2.9)	.02
Reentry injury, n (%)	39 (9.1)	30 (8.4)	9 (13)	.21

FREDO, First redo surgery; *MREDO,* multiple redo surgery; *CABG,* coronary artery bypass grafting; *CPB,* cardiopulmonary bypass; *SD,* standard deviation; *IABP,* intra-aortic balloon pump; *ECMO,* extracorporeal membrane oxygenation.

TABLE 4. Postoperative outcomes

Outcome	Entire sample (n = 429)	FREDO (n = 360)	MREDO (n = 69)	*P* value
30-d mortality, n (%)	58 (13.8)	43 (12.3)	15 (21.7)	.03
CVA, n (%)	20 (4.7)	16 (4.4)	4 (5.8)	.75
New renal failure, n (%)	50 (11.7)	39 (10.8)	11 (15.9)	.22
New dialysis, n (%)	36 (8.4)	26 (7.2)	10 (14.5)	.04
Deep sternal infection, n (%)	0 (0)	0 (0.0)	0 (0.0)	-
Postoperative atrial fibrillation, n (%)	125 (29.1)	100 (27.8)	25 (36.2)	.15
Postoperative pneumonia, n (%)	26 (6.1)	24 (6.7)	2 (2.9)	.27
Heart block requiring pacemaker, n (%)	14 (3.3)	11 (3.1)	3 (4.3)	.70
Blood transfusion, n (%)	423 (98.6)	354 (98.3)	69 (100.0)	.60
Reexploration for hemorrhage, n (%)	46 (10.7)	38 (10.6)	8 (11.6)	.79
Length of stay (d), median, (Q1-Q3)	8.0 (5.0-12.0)	8.0 (5.5-12.0)	7.0 (5.0-12.0)	.17
ICU stay (h), median (Q1-Q3)	90.5 (43.5-159.8)	92.0 (44.0-160.0)	75.4 (42.2-153.0)	.19

FREDO, First redo surgery; *MREDO,* multiple redo surgery; *CVA,* cardiovascular accident; *ICU,* intensive care unit.

frequencies in both groups. Femoral venous cannulation either before reopening the sternotomy (n = 2) or expeditious conversion (n = 48) was used in 50 patients and more commonly in the MREDO group. The incidence of reentry injury was 8.4% in the FREDO group and 13% in the MREDO group, and the difference was not statistically significant. Only 2 injuries were to previous patent grafts. Of the 39 cases of reentry injury, approximately half of them (n = 20) required emergency peripheral cannulation for CPB and cooling along with temporary sternal closure to tamponade bleeding, and 6 (15.3%) of them did not survive the operation. For 2 patients, we initiated CPB and cooling before opening the chest due to proximity of aorta to the sternum noted on preoperative CT scans. For cases that required hypothermic circulatory arrest, antegrade cerebral perfusion was more commonly used than retrograde cerebral perfusion. Intra-aortic balloon pump (IABP) was used in 108 patients (25.2%) and with similar frequency in both groups. Extracorporeal membrane oxygenation was needed in 2 patients in the MREDO group as extreme salvage option in patients dying in the immediate postoperative period. The 30-day mortality for the entire cohort was 13.8% (n = 58). Of these, 47 (11%) were operative deaths.

Postoperative Complications

Comparisons of postoperative morbidity and mortality are listed in Table 4. The 30-day mortality (including operative deaths) was higher at 21.7% in the MREDO group compared with 12.3% in the FREDO group ($P = .03$). A higher need for dialysis in the MREDO group was observed (8.4% vs 7.2%, $P = .04$). The incidence of postoperative neurologic events (cerebrovascular accidents such as stroke and transient ischemic attacks, seizures), renal failure, pneumonia, postoperative atrial fibrillation, and heart block was similar between the groups. Neither group had any occurrence of deep sternal wound infection. Reexploration for bleeding was similar between the groups (10.6% vs 11.6%, $P = .79$). Median length of stay was similar at 8.0 (5.5-12.0) days in the FREDO group versus 7.0 (5.0-12.0) days in the MREDO group ($P = .28$) and so was the time spent in the intensive care unit.

Risk Factors for 30-Day Mortality and Increased Length of Stay

Univariable regression analyses identified age, severe chronic lung disease, prior myocardial infarction, Class 3 or 4 NYHA heart failure, previous CABG, CPB time, IABP use, concomitant CABG, and MREDO as risk factors for 30-day mortality (Table 5). Of note, history of previous aortic surgery or sustaining a reentry injury did not influence mortality. In the multivariable analysis, age, CPB time, use of IABP, and MREDO remained significant risk factors for 30-day mortality. Notably, mortality risk increased with each additional reoperation: The first redo had a risk of 12.3%, which increased to 20.3% with the second redo and with highest risk at the third redo surgery of 31%. Longer length of stay was associated with blood transfusions, postoperative dialysis, postoperative atrial fibrillation, hypertension, previous aortic valve surgery, absence of previous CABG circulatory arrest time, and longer intensive care unit stay.

Survival

Survival probabilities are plotted against the time since the date of surgery in Figure 1, and the log-rank test does not suggest an overall difference in survival between the 2 groups. However, the survival advantage of FREDO over MREDO in the first 2 years is apparent. This observation is supported by the significant difference in 30-day mortality (Table 4). The 5-year and 10-year survival probabilities

TABLE 5. Risk factors for 30-day mortality

Univariable analysis				
Risk factor	Risk ratio	Lower RR	Upper RR	*P* value
Age	1.04	1.02	1.06	<.0001
Male	0.64	0.39	1.03	.07
Cerebrovascular disease	1.47	0.87	2.46	.14
Chronic lung disease (severe)	1.97	1.03	3.78	.03
Diabetes	1.31	0.72	2.40	.36
Dyslipidemia	1.16	0.70	1.92	.54
Hypertension	1.51	0.71	3.19	.27
Renal failure dialysis	1.44	0.24	8.50	.68
Prior MI	1.99	1.15	3.44	.01
Ejection fraction	0.98	0.96	1.00	.07
Smoking	1.15	0.71	1.86	.55
NYHA Class I-II	0.67	0.37	1.20	.17
NYHA Class III-IV	1.97	1.22	3.16	.004
History of CABG	1.87	1.13	3.09	.01
History of aortic surgery	1.47	0.91	2.38	.10
History of AVR	0.92	0.56	1.49	.73
History of other cardiac procedures	3.80	1.82	7.94	.0004
Time between index and previous surgery	1.14	0.69	1.90	.59
CPB time	1.01	1.00	1.01	<.0001
Crossclamp time	1.00	0.99	1.01	.09
Circulatory arrest	0.97	0.59	1.57	.90
IABP	5.98	3.62	9.89	<.0001
ECMO	3.65	0.89	14.93	.07
Reentry injury	1.41	0.69	2.88	.34
Concomitant CABG	2.93	1.84	4.65	<.0001
First vs multiple redo	1.76	1.04	3.00	.03
Multivariable analysis				
Risk factor	**Risk ratio**	**Lower RR**	**Upper RR**	***P* value**
Age	1.23	1.18	1.4	<.0001
CPB time	1.49	1.17	1.9	.0012
IABP	3.94	2.34	6.61	<.0001
First vs multiple redo	1.98	1.22	3.20	.006

Lower and upper RR reflect the upper and lower bounds of the 95% CI. *RR,* Risk ratio; *MI,* myocardial infraction; *NYHA,* New York Heart Association; *CABG*, coronary artery bypass grafting; *AVR,* aortic valve replacement; *CPB*, cardiopulmonary bypass; *IABP,* intra-aortic balloon pump; *ECMO*, extracorporeal membrane oxygenation.

were 73.7% and 62.9% in the FREDO group versus 71.7% and 66.6% in the MREDO group, respectively. Finally, the Kaplan–Meier curves suggest that MREDO has better survival at 15 years, but the difference in survival is difficult to evaluate because of the small number of patients remaining in the risk set beyond 10 years.

DISCUSSION

Redo aortic surgery is technically challenging and is being increasingly performed across the world. In the current series, we demonstrated a 12% to 21% mortality risk with redo aortic surgery. Overall, in-hospital mortality has ranged from 11% to 15% for redo aortic operations in the literature,[3-7,9] which is similar to the current results. Di Bartolomeo and colleagues[10] reported a hospital mortality of 12.1% in an analysis of 224 patients after previous aortic surgery. In 2007, Szeto and colleagues[11] reported a 11.5% mortality rate in 156 patients who underwent reoperative aortic root surgery. Data comparing aortic surgery performed in the setting of multiple previous cardiac operations are limited.

The 30-day mortality rate of the entire cohort was 13.8%, but was significantly higher at 21.7% in the MREDO group. It is worth noting that one-third

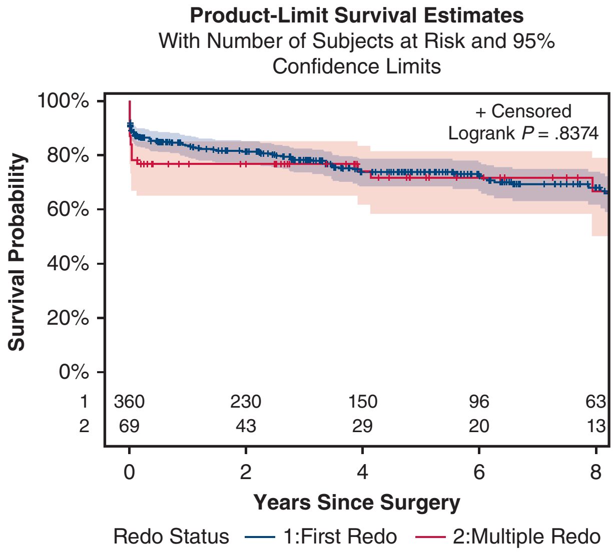

FIGURE 1. Kaplan–Meier estimates of survival between aortic surgery performed as FREDO and MREDO.

(34.3%) of this cohort had NYHA Class 3 to 4 heart failure preoperatively, and 21.7% had a previous CABG suggesting the presence of preexisting ischemic heart disease. This was probably also the reason for high IABP use (25%) in this cohort. Additionally, approximately 50% of this cohort also had aortic arch surgery (hemiarch, zone 2 arch or total arch), thus adding to the complexity and operative time. Despite several preoperative risk factors, the rates of postoperative complications are relatively low. In addition, despite the presence of previous cerebrovascular disease in 22% of the population, the overall perioperative stroke rate was low at 4.7%.

To our knowledge, this is the first study that examines the differential impact of number of previous cardiac operations on outcomes of redo aortic surgery. As seen from the data, the chances of mortality are higher with increasing number of previous cardiac operations and the incidence of new dialysis requirement also increased with multiple redo surgeries, but other postoperative morbidity and length of stay are more or less similar (Figure 2). MREDO also was an independent predictor of 30-day mortality. On further analysis, we found that 13 of 15 total 30-day deaths in the MREDO group were actually operative, which amounts to an operative risk of 18.9% for 2 or more redo surgeries. A 10% increase in risk was observed with each redo operation up to the third redo surgery. However, given the relatively small sample size, it was not possible to determine the number of operations beyond which operative risk becomes prohibitive. Notably, almost all of these patients had a concomitant arch replacement or mitral/tricuspid valve replacements, which added to the CPB time. Despite these findings, 5-year survival was similar between the groups: 73.7% in the FREDO group and 68.7% in the MREDO group. This is comparable to 72.5% reported by the Bologna group,[10] 72.6% reported by Szeto and colleagues,[11] and 66% reported by Estrera and colleagues.[4] These numbers are also similar to survival after primary proximal aortic surgery reported in the literature.[9,12]

Age, CPB time, IABP use, postoperative cerebrovascular accident and MREDO were identified as independent risk factors for 30-day mortality in the current series. Prolonged CPB time is no doubt a surrogate marker for increased procedural complexity associated with added concomitant procedures or a reentry injury that required establishing peripheral cannulation and CPB early in the dissection process. These findings are similar to the group from Bologna and other groups that also identified CPB time as a prognostic factor for mortality along with active endocarditis and NYHA Class III and IV heart failure.[5,10] The study by Sandhu and colleagues[6] identified the presence of coronary artery disease as a risk factor for mortality. Szeto and colleagues[11] identified age more than 75 years and NYHA Class IV heart failure as independent predictors of mortality, whereas Estrera and colleagues[4] also identified CPB time as an independent risk factor for mortality along with COPD and renal dysfunction.

In the current era, critical factors and skills exist that are essential for effectively navigating these complex open operations and achieving optimal clinical outcomes. For example, the ability to perform peripheral cannulation, adequate knowledge of various cerebral protection strategies, and being able to initiate extracorporeal membrane oxygenation as a potential salvage procedure are a few examples of the expertise required for successfully performing reoperative aortic procedures. The importance of preoperative CT imaging in planning these complex cases cannot be overemphasized and in the opinion of the authors should always be performed.

Elective peripheral cannulation for the purpose of safe sternal reentry is not routinely performed in our group. One reason for this practice pattern is the small, but inherent risk associated with peripheral vascular access. The other primary factor is the increased CPB time that would result as a consequence of initiating CPB before sternal reentry.

Previous data have demonstrated that CPB time is associated with worsening morbidity and mortality and poor clinical outcome.[13,14] Preemptive peripheral cannulation certainly cannot prevent critical cardiac injury during sternal reentry.[14] As a result, only patients with complex and extremely high-risk anatomy and expected injury should be cannulated preemptively.[15] Otherwise, in patients at moderate risk of reentry cardiac injury, peripheral sites, such as axillary artery exposure and cannulation as well as obtaining peripheral venous access can be prepared

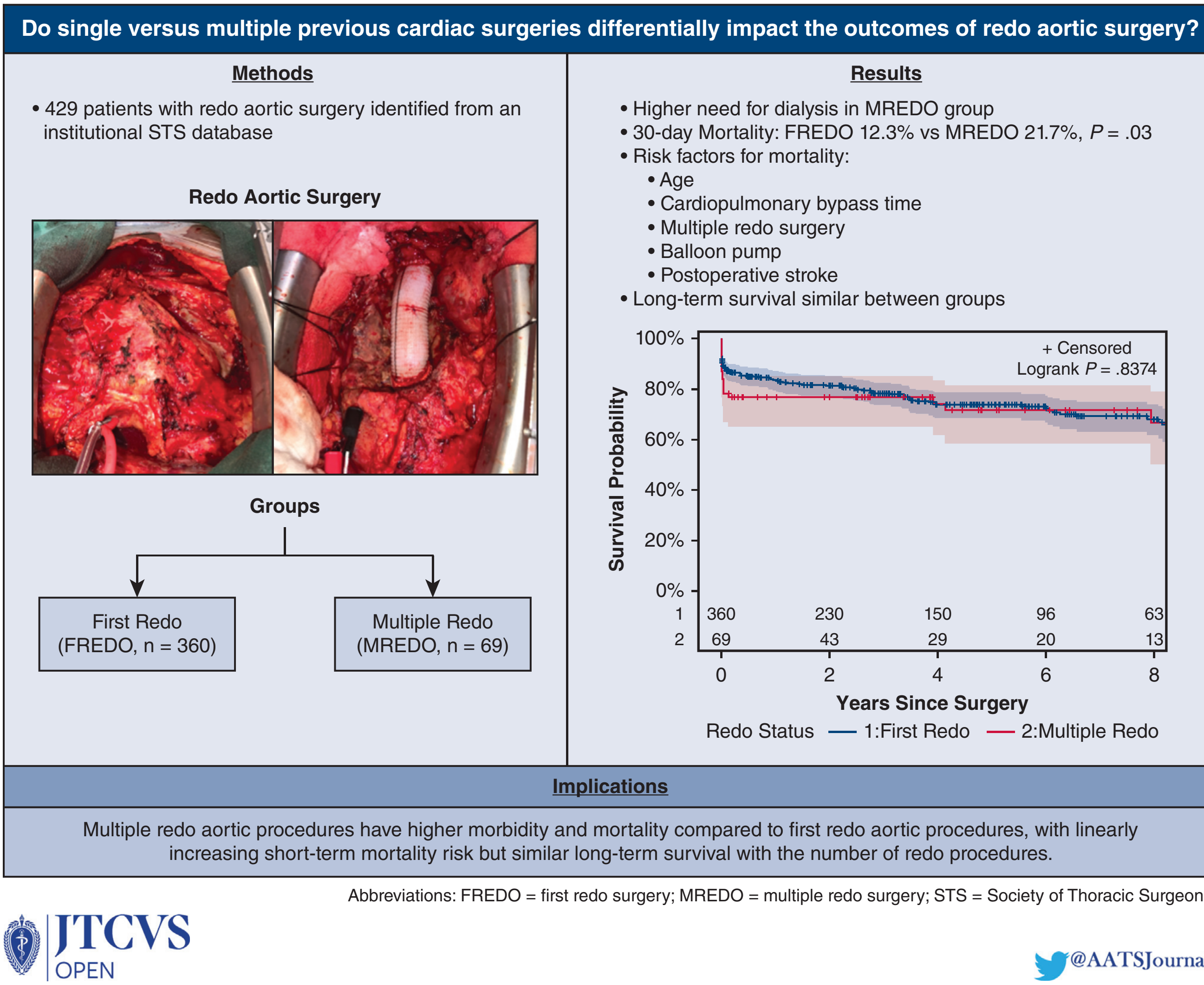

FIGURE 2. Comparative outcomes of FREDO versus MREDO aortic surgery.

before redo sternotomy to facilitate expeditious initiation of CPB in the event of cardiac injury.

Another question that arises when operative risk appears prohibitive in case of multiple previous operations, is the potential feasibility of performing an ascending aortic endovascular procedure grafting for such patients. Although still in early investigation and development, success with endovascular repair of proximal aortic pseudoaneurysms and dissections has been reported in individual series of high-risk patients.[16,17] With rapid development of endovascular techniques, these technologies will need to be further investigated for consistent use in such a patient population.

Study Limitations

As with any retrospective study, our study has limitations and potential selection bias. Our follow-up is not complete and data for reinterventions after the index surgery are inconsistent and therefore not included. Given the relatively small sample size, particularly in the MREDO group, propensity score matching was not possible to address the between-group imbalance in preoperative characteristics. Additionally, the small number of events may leave statistical comparisons underpowered to detect differences in outcome.

CONCLUSIONS

Redo aortic procedures can be done with 12% to 21% risk of mortality, despite the complex etiologies being addressed at a high-volume aortic center (Video 1). Operative risk increases with increasing number of previous cardiac operations, whereas the risk of postoperative complications, length of stay, and long-term survival are comparable between 1 versus multiple previous redo operations. Given that age, CPB time, postoperative cerebrovascular accident,

VIDEO 1. Discussion of the article. Video available at: https://www.jtcvs.org/article/S2666-2736(23)00308-X /fulltext.

and IABP use were independent predictors of 30-day mortality, preoperative preparation to assess the risk and careful operative planning to minimize these variables is imperative to improve patient outcomes.

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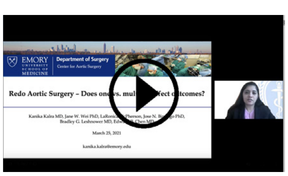

Conflict of Interest Statement

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.

The authors thank Iman Aziz, MBBch, MBA, for identifying patients in the Society of Thoracic Surgeons database at our institution.

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Key Words: first redo, multiple redo, redo aortic surgery