European Journal of Medical Research

RESEARCH

Open Access

Short- and mid-term outcomes after redo surgical valve replacement

Pardis Sadeghi[1], Ali Hosseinsabet[1], Reza Mohseni-Badalabadi[1*], Arash Jalali[2,3], Ahmad Vakili-Basir[2,3], Mina Pashang[4], Negar Omidi[1], Jamshid Bagheri[5] and Mohammadjavad Mehrabanian[6]

Abstract

Background While previous studies have indicated comparable outcomes for redo surgical valve replacement (SVR) and primary SVR, there is limited information regarding the long-term follow-up of these patients. Providing prognostic data on redo SVR is crucial for enhancing decision-making and medical care, as well as for identifying low-risk subsets of patients eligible for redo SVR. This study aimed to evaluate the short- and mid-term outcomes of patients who underwent their first and second redo SVR of a previously replaced valve.

Methods We included 118 consecutive patients with a history of first or second redo SVR. The participants had a mean age of 57.5 ± 14.4 years, with 71 (60%) being female. The median follow-up period was 69 months. Clinical, intraoperative, and laboratory data were analyzed to assess all-cause mortality, major adverse events (MAE), and a composite of prosthetic valve thrombosis, embolic events, and major hemorrhage (TEH), along with their predictors. Bayesian model averaging was used for statistical analysis.

Results The 30-day mortality rate was 11 patients (9.3%). Chronic kidney disease was identified as an independent predictor of 30-day mortality. The overall survival rates at one and five years were 86% (95% CI 80% to 93%) and 76% (95% CI 68% to 85%), respectively. Dyslipidemia, a history of major bleeding, chronic kidney disease, stroke, and transvalvular leakage in biological prostheses were all associated with all-cause mortality as independent predictors. The TEH-free survival rates at one and five years were 91% (95% CI 86% to 97%) and 79% (95% CI 71% to 88%), respectively. Diabetes, sex, a history of percutaneous coronary intervention, and baseline functional capacity were identified as independent predictors for the occurrence of TEH. The MAE-free survival rates at one and five years were 82% (95% CI 73% to 92%) and 61% (95% CI 49% to 75%), respectively. Hypertension and baseline functional class were independent predictors of MAE occurrence. The type and anatomical position of the valve were not predictors of mortality, THE, and MAE.

Conclusions Our study demonstrated acceptable short- and mid-term outcomes for redo SVR, especially in patients without significant risk factors. Several potential predictors of adverse outcomes were identified.

Keywords Prosthetic valve, Valve replacement, Mortality, Redo surgery, Prognosis

*Correspondence:
Reza Mohseni-Badalabadi
mohsenihr@yahoo.com
Full list of author information is available at the end of the article

Introduction

Valvular heart diseases are estimated to affect more than 70 million people worldwide [1]. Rheumatic valvular disease primarily impacts populations in developing countries, while degenerative valve disease affects both developing and developed nations, with an increasing prevalence [1, 2]. Surgical valve replacement (SVR), which includes mitral valve replacement (MVR), aortic valve replacement (AVR), tricuspid valve replacement, and pulmonary valve replacement, has been a widely accepted treatment method for various valvular heart diseases for several decades [3] and has been performed on millions of patients worldwide [4].

In developing countries, SVR is predominantly performed on younger patients due to the higher prevalence of rheumatic valvular disease [5], with favorable survival rates observed following AVR [6] and MVR [7]. It is estimated that up to one-third of patients with prosthetic valves will require redo valve intervention at some point [8]. Over the past two decades, transcatheter valve replacement has emerged as a viable alternative to redo SVR in cases involving biological prostheses [9]. Nonetheless, SVR remains the only option for conditions such as mechanical prostheses, endocarditis, and certain instances of valve thrombosis or paravalvular leakage [10]. Moreover, transcatheter valve replacement is often inaccessible to patients in low-income countries. Additionally, for AVR [11] and MVR [12], one-year survival rates have not shown significant differences between SVR and transcatheter valve replacement. Previous studies have demonstrated comparable prognoses for redo SVR and primary SVR in the cases of MVR [13] and AVR [14, 15], highlighting the importance of identifying low-risk patient subsets for redo SVR to assist clinicians in making informed decisions. However, limited data are available on the long-term follow-up of patients undergoing redo SVR. Existing studies on redo AVR are often outdated [16, 17], even though outcomes have significantly improved over time [18]. Moreover, these studies frequently focus on specific age groups [19], valve types [20], or patient demographics [21], and may examine redo sternotomy for reasons unrelated to valvular replacement or for valves other than the aortic valve [18]. Therefore, it is essential to provide current prognostic data on redo SVR to facilitate informed decision-making and improve medical care by developing tailored approaches for redo SVR.

This study aimed to evaluate the short- and mid-term outcomes of patients who underwent their first and second redo SVR of the same previously replaced valve.

Methods

Study population

In our historical cohort study, 118 patients underwent first and second redo SVR of the same previously replaced valve at our tertiary referral cardiovascular center between April 2011 and April 2023. Redo SVR was defined as the replacement of the same valve replaced previously. Primary SVR and first and second redo SVR may have been performed alongside other cardiac surgeries in addition to the redo replacement of the same valve. Consequently, patients with a history of valve replacement who underwent the replacement of other valves were excluded from the study. Additional cardiac surgeries were not considered primary cardiac surgeries. Furthermore, patients with a history of valve repair or valve thrombectomy were excluded. The type of prosthetic valve was selected according to a discussion among cardiologists, cardiac surgeons, and patients while considering patients'socioeconomic status that determined the possibility of frequent prothrombin time checking, childbearing age, the tendency of patients for one type of prosthetic valve after full discussion regarding relative merits of each type of prosthetic valve, and validated recommendations. The patient data at the time of the first or second redo SVR were recorded.

In our hospital, patients who undergo cardiac valve surgeries are monitored in a dedicated unit, and their data are collected systematically. Patients receive regular follow-up visits and undergo echocardiography when indicated. Medical treatment is provided based on validated recommendations.

In this study, follow-up data, including demographic, clinical, surgical, and short- and mid-term outcomes, until September 2023 were reviewed. Chronic kidney disease was defined as serum creatinine > 4 mg/dL. Dyslipidemia was identified based on the use of anti-lipid medications or laboratory parameters, including triglyceride > 150 mg/dL, total cholesterol > 200 mg/dL, and high-density lipoprotein < 45 mg/dL in men and < 55 mg/dL in women. Outcomes were defined as all-cause mortality; a composite measure including valve thrombosis, embolic events, and major hemorrhage (TEH); and nonstructural valve dysfunction, encompassing paravalvular leakage, patient-prosthesis mismatch, and pannus formation. A composite of all-cause mortality, TEH, endocarditis, re-operation, pacemaker implantation, and mediastinitis was defined as major adverse events (MAE).

We adhered closely to the guideline recommendations for reporting outcomes following cardiac valve surgeries [22]. Our institutional review board approved the research study and confirmed that the informed written consent obtained at the time of admission was sufficient.

Statistical analysis

This study utilized standard descriptive statistics, expressing normally distributed quantitative variables as means and standard deviations, while abnormally distributed quantitative variables were reported as medians with interquartile ranges (IQRs). Qualitative variables were depicted using frequencies and percentages.

The effects of individual variables on all-cause mortality, TEH, and MAE were examined using Cox Proportional Hazard Regression, while logistic regression was employed to evaluate their impact on 30-day mortality and nonstructural valve dysfunction. Concerning MAE, since most of the occurrences were in women, the analysis was conducted solely for female participants to comply with model assumptions.

The constraint of limited events for multivariable analysis was overcome by implementing the Bayesian model averaging (BMA) to identify the most significant predictors (Supplementary Figs. 1–5). This method addresses model uncertainty by generating multiple candidate models and averaging their results based on posterior probabilities. Variables are evaluated based on their inclusion probabilities across models, and those exceeding a specified threshold (e.g., 0.5) are selected. This approach reduces the risk of overfitting and improves model stability. The variables whose corresponding bar is more filled in in BMA figures are more important predictors whose effect should be adjusted. Then a multivariable Cox proportional hazards (PH) model or multivariable logistic regression was applied, as appropriate. Schoenfeld residuals and the Hosmer–Lemeshow test were used to evaluate the PH assumption and assess the model's goodness of fit. In addition, the concordance index (C-index) and area under the curve (AUC) were selected to measure the Cox-PH and logistic model's discriminative ability, which assesses how well the model can distinguish between outcomes. A C-index and AUC greater than 0.7 reflect good discrimination of the model. The outcomes were presented as hazard ratios (HRs) and odds ratios (ORs) with 95% confidence intervals (CIs) for the Cox and logistic regression models, respectively. Data analysis was performed using the R Statistical language (version 4.4.0; R Core Team, 2023).

Results

Patient demographics, clinical, intraoperative, and other characteristics are summarized in Table 1. The age of our patients was 57.5 ± 14.4 years, and 71 (60%) were female. Thirteen patients (11%) had a history of second redo SVR. 11 cardiac surgeons did the surgeries. The cardiac surgeons had 10 years (4–17 y) of experience at the beginning of our study and performed 81 (49–167) valve surgeries annually. All surviving patients were successfully followed up after hospital discharge. The median follow-up for these patients was 69 months (55–82 months). The median time interval between primary surgery and first redo SVR was 5.0 years (3.0–12.1 years), primary and second redo SVR was 14.8 years (10.3–24.2 years), and second and third redo SVR was 8.3 years (4.7–13.9 years). The underlying pathologic causes for first or second redo SVR included infectious endocarditis in 31 patients (26%), valve thrombosis in 34 (29%), pannus formation in 7 (6%), paravalvular leakage in 10 (8%), patient-prosthesis mismatch in 1 (1%), and valve degeneration in 35 (30%).

Table 1 The characteristics of the study population

Characteristics	Statistical description[a]
Number of patients (n)	118
Sex (female), %	71 (60.1)
Age, y	57.5 ± 14.4
Body mass index, kg/m^2	25.7 ± 4.5
Diabetes, %	21 (17.8)
Hypertension, %	35 (29.7)
Dyslipidemia, %	34 (28.8)
Cigarette smoking, %	13 (11)
Chronic kidney disease, %	6 (5.1)
History of coronary artery bypass graft surgery, %	6 (5.1)
History of myocardial infarction, %	6 (5.1)
History of stroke, %	20 (16.9)
History of percutaneous coronary intervention, %	7 (5.9)
History of major bleeding, %	9 (7.6)
Atrial fibrillation rhythm, %	46 (39.0)
NYHA functional class III, IV, %	37 (31.46)
Second redo surgery, %	13 (11.0)
Primary valve type (mechanical), %	68 (57.6)
First or second redo valve type (biologic), %	45 (38.1)
Aortic valve replacement, %	31 (26.3)
Mitral valve replacement, %	77 (65.3)
Transvalvular leakage (in biological prostheses), %	18 (15.3)
Creatinine, mg/dL	0.9 ± 0.2
Hemoglobin, g/dL	12.3 ± 2.2
Left ventricular ejection fraction, %	49.0 ± 8.0
Systolic pulmonary artery pressure, mm Hg	51.0 ± 16.0
Cross-clamp time, min	71.5 (48.0, 103.3)
Perfusion time, min	115.0 (77.3, 175.8)

NYHA: New York Heart Association.

[a] The continuous variables, if normally distributed, are presented as means and standard deviations and, if skewed, demonstrated as medians and interquartile ranges. Categorical variables are presented as frequencies (n) and percentages (%)

Concomitant surgeries performed during the first or second redo AVR included aortoplasty in four patients and coronary artery bypass graft surgery in six patients. For the first or second redo MVR, the concomitant surgeries were as follows: AVR in five patients, aortic valve repair in one patient, tricuspid valve replacement in three patients, tricuspid valve repair in fifteen patients, pulmonary valve replacement in one patient, coronary artery bypass graft surgery in eight patients, atrial septal defect closure in two patients, and paravalvular leakage closure in one patient. Additionally, for the first or second redo TVR, there was valve thrombectomy for the other prosthetic valve in one patient, paravalvular leakage of the other prosthetic valve in one patient, and coronary artery bypass graft surgery in one patient.

The frequencies of valve replacement locations and types of prosthetic valves used in primary surgery, first redo SVR, and second redo SVR are presented in Table 2, while their sizes and brands are detailed in Supplementary Table 1. Emergent or urgent surgeries were performed on eight patients (7%). An intra-aortic balloon pump was inserted in five patients (4%). Intraoperative and postoperative inotropic agents were administered to 30 patients (25%) and 24 patients (20%), respectively. Blood transfusions were conducted intraoperatively in 34 patients (29%) and postoperatively in 59 patients (50%).

During the first 30 days after the operation, 11 patients (9.3%) died, with 10 of these deaths occurring before hospital discharge. Our univariable analysis identified hypertension (OR, 4.94; 95% CI 1.93 to 20.1; P = 0.016), chronic kidney disease (OR, 30.00; 95% CI 5.01 to 246.00; P < 0.001), history of TEH (OR, 6.31; 95% CI 1.17 to 29.30; P = 0.021), baseline New York Heart Association (NYHA) functional class III/IV (OR, 4.49; 95% CI 1.26 to 18.20; P = 0.023), creatinine levels (OR, 1.30; 95% CI 1.03 to 1.66; P = 0.023), and redo MVR (OR, 0.27; 95% CI 0.07 to 0.94; P = 0.045) as predictors of 30-day mortality. The age, other coronary artery risk factors, second redo SVR, left ventricular ejection fraction, prosthetic valve type, and perfusion time were not significant predictors of early mortality (Supplementary Table 2). Our multivariable analysis demonstrated chronic kidney disease (OR, 22.50; 95% CI 3.44 to 196.00; P = 0.002) as an independent predictor of 30-day mortality (Table 3 and Fig. 2A).

The most common morbidities observed during the follow-up period after the last surgery included stroke in seven patients (6%), major bleeding in nine (8%) (two with soft tissue hematoma and seven with gastrointestinal bleeding), and valve thrombosis in five (4%). Other complications included permanent pacemaker placement due to heart block in one patient (1%), infective endocarditis in four (3%), and mediastinitis in one (1%). Paravalvular leakage was identified in 12 patients (10%) and patient-prosthesis mismatch in three (3%), while pannus formation was not detected in any patients. Reoperation was done on four patients (3%; two for infective endocarditis, one for patient-prosthesis mismatch, and one for valve thrombosis).

At the end of the follow-up period, 80 patients (68%) had survived. The survival rate for patients alive after 30 days was 86% (95% CI 80% to 93%) at one year and 76% (95% CI 68% to 85%) at five years (Fig. 1A).

Our univariable analysis identified male sex (HR, 2.43; 95% CI 1.27 to 4.68; P = 0.008), hypertension (HR, 1.92; 95% CI 1.01 to 3.64; P = 0.019), chronic kidney disease (HR, 7.44; 95% CI 2.52 to 21.90; P < 0.001), history of major bleeding (HR, 3.78; 95% CI 1.56 to 9.18; P = 0.003), creatinine levels (HR, 1.23; 95% CI 1.11 to 1.37; P < 0.001), transvalvular leakage in biological prostheses (HR, 0.11; 95% CI 0.02 to 0.83; P = 0.032), and biological primary valves (HR, 0.51; 95% CI 0.26 to 0.99; P = 0.048) as predictors of all-cause mortality. The age, other coronary artery risk factors, left ventricular ejection fraction, and perfusion time were not significant predictors of

Table 2 The distribution of mechanical prosthetic and bioprosthetic valves according to the valve position and the time of surgery

Place of valve replacement	Frequencies	Primary Surgery		Redo SVR			
				First		Second	
		M	B	M	B	M	B
Mitral valve replacement, %	73 (62)	42	31	43	22	3	5
Aortic valve replacement[a], %	27 (23)	19	8	19	3	4	0
Tricuspid valve replacement, %	11 (9)	5	6	0	10	0	1
Pulmonary valve replacement, %	3 (3)	3	0	1	2	0	0
Mitral and aortic valve replacement, %	4 (3)	0	4	3	1	0	0
Total	118 (100)	69	50	66	38	7	6

[a] The type of one aortic valve prosthesis was missed

B; Bioprosthetic valve, M; Mechanical prosthetic valve, SVR; Surgical valve replacement

Table 3 The multivariable analyses of study outcomes

Outcome	Characteristics	HR [OR] (95% CI)[a]	P value
30-day mortality[b]			
	Chronic kidney disease	22.50 (3.44, 196.00)	0.002
All-cause mortality[c]			
	Dyslipidemia	0.42 (0.18, 0.95)	0.036
	History of major bleeding	4.79 (1.75, 13.10)	0.002
	Chronic kidney disease	20.40 (5.59, 74.50)	< 0.001
	Stroke	2.80 (1.27, 6.17)	0.011
	Transvalvular leakage in biological prosthesis	0.07 (0.010, 0.056)	0.012
Composite of thrombosis of a valve, embolic events, and major hemorrhage[d]			
	Diabetes	4.33 (1.65, 11.40)	0.003
	NYHA functional class III/IV	0.07 (0.01, 0.53)	0.010
	Sex (male)	0.18 (0.05, 0.69)	0.012
	History of percutaneous coronary intervention	8.13 (1.56, 42.50)	0.013
Major adverse events[e]			
	Hypertension	2.90 (1.25, 6.72)	0.013
	NYHA functional class III, IV	0.24 (0.07, 0.82)	0.023

CI: Confidence interval, HR: Hazard ratio, OR: Odds ratio, NYHA: New York Heart Association

[a] OR for 30-day mortality, HR for Other outcomes

[b] The Hosmer–Lemeshow goodness-of-fit test: ($\chi_2^2 = 4.55$, P = 0.102), AUC with 95% CI 0.82 (0.68 to 0.96)

[c] Proportional hazard assumption: ($\chi_4^2 = 4.56$, P = 0.47), C-Index with 95% CI 0.74 (0.68 to 0.89)

[d] Proportional hazard assumption: ($\chi_4^2 = 3.13$, P = 0.189), C-Index with 95% CI 0.78 (0.71 to 0.86)

[e] Proportional hazard assumption: ($\chi_4^2 = 1.06$, P = 0.591), C-Index with 95% CI 0.69 (0.63 to 0.81)

all-cause mortality (Supplementary Table 2). Our multivariable analysis demonstrated dyslipidemia (HR, 0.42; 95% CI 0.18 to 0.95; P = 0.036), history of major bleeding (HR, 4.79; 95% CI 1.75 to 13.10; P = 0.002), chronic kidney disease (HR, 20.40; 95% CI 5.59 to 74.50; P < 0.001), stroke (HR, 2.80; 95% CI 1.27 to 6.17; P = 0.011) and transvalvular leakage in biological prostheses (HR, 0.07; 95% CI 0.01 to 0.56; P = 0.012) as independent predictors of all-cause mortality (Table 3 and Fig. 2B).

The MAE-free survival rate at one and five years was 82% (95% CI 73% to 92%) and 61% (95% CI 49% to 75%), respectively (Fig. 1C). Our univariate analysis identified diabetes (HR, 2.85; 95% CI 1.28 to 6.32; P = 0.010), baseline NYHA functional class III/IV (HR, 0.25; 95% CI 0.08 to 0.83; P = 0.024), as predictors of MAE (Supplementary Table 3). The age, other coronary artery risk factors, chronic kidney disease, second redo SVR, left ventricular ejection fraction, and prosthetic valve type, were not significant predictors of MAE. Our multivariable analysis ascertained hypertension (HR, 2.90; 95% CI 1.25 to 6.72; P = 0.013) and baseline NYHA functional class III/IV (HR, 0.24; 95% CI 0.07 to 0.82; P = 0.023) as independent predictors of MAE (Table 3 and Fig. 2C).

The TEH-free survival rate at one and five years was 91% (95% CI 86% to 97%) and 79% (95% CI 71% to 88%), respectively (Fig. 1B). Our univariable analysis identified diabetes (HR, 3.46; 95% CI 1.36 to 8.83; P = 0.009), baseline NYHA functional class III/IV (HR, 0.12; 95% CI 0.02 to 0.87; P = 0.036), and male sex (HR, 0.28; 95% CI 0.08 to 0.96; P = 0.043) as predictors of TEH (Supplementary Table 3). The age, other coronary artery risk factors, chronic kidney disease, left ventricular ejection fraction, and prosthetic valve type, were not significant predictors of TEH. Our multivariable analysis demonstrated diabetes (HR, 4.33; 95% CI 1.65 to 11.40; P = 0.003), baseline NYHA functional class III/IV (HR, 0.07; 95% CI 0.01 to 0.53; P = 0.010), male sex (HR, 0.18; 95% CI 0.05 to 0.69; P = 0.012), and history of percutaneous coronary intervention (HR, 8.13; 95% CI 1.56 to 42.50; P = 0.013) as independent predictors of TEH occurrence (Table 3 and Fig. 2D). Our univariate analysis distinguished smoking (OR, 4.22; 95% CI 1.00 to 15.80; P = 0.036), as a predictor of nonstructural valve dysfunction (Supplementary Table 4).

Discussion

Redo SVR is an unavoidable procedure in some patients with mechanical valve thrombosis, paravalvular leakage, other cardiac surgery-requiring conditions, or the unavailability of transcatheter valve replacement. Given the diverse patient population in need of SVR, investigating this field is crucial.

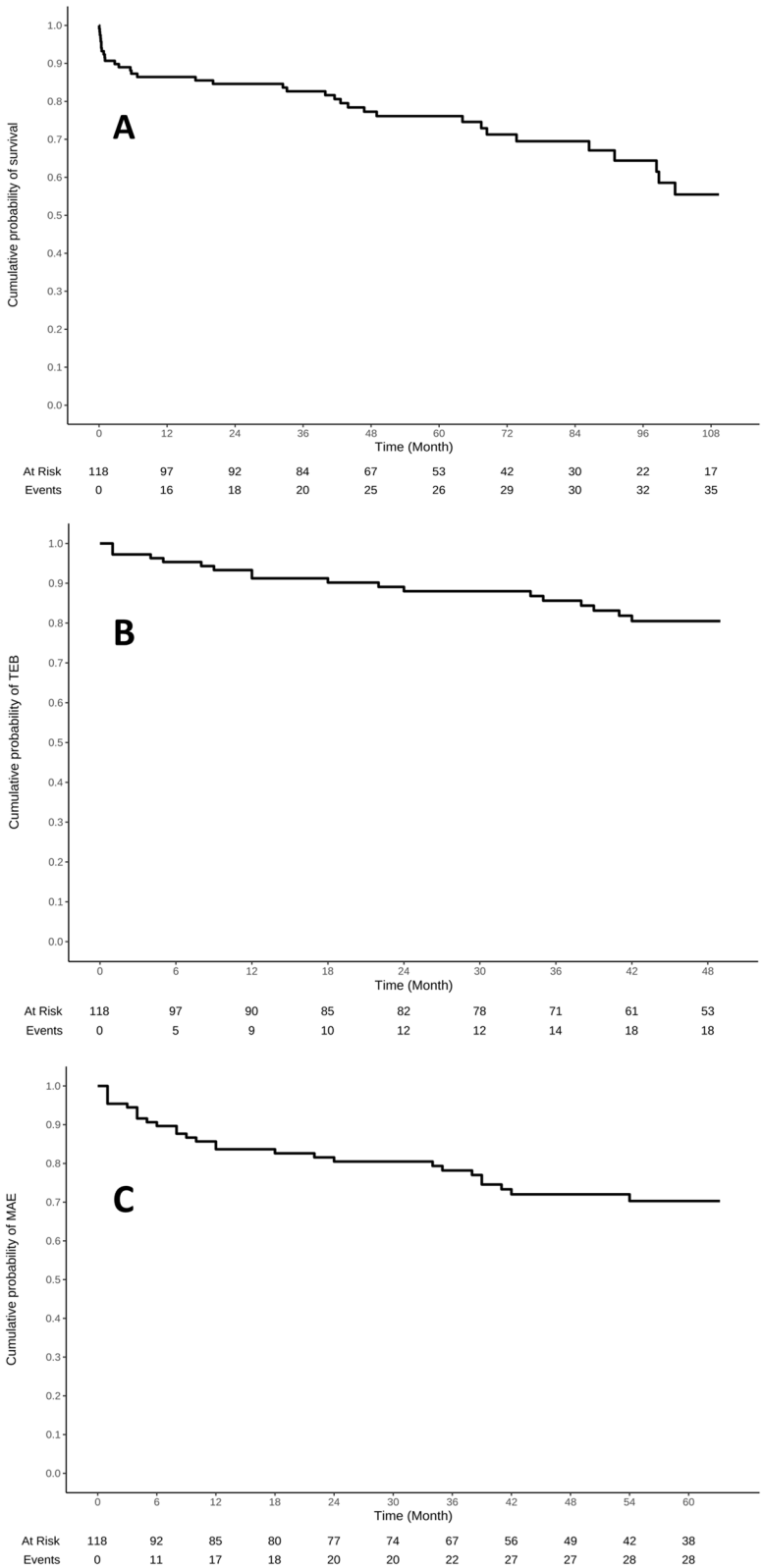

Fig. 1 The images illustrate **A** the actuarial overall survival; **B** a composite of valve thrombosis, embolic events, and hemorrhage-free survival after the first and second redo surgical valve replacement operations; and **C** major adverse event-free survival rates. MAE; Major adverse event, TEB; Valve thrombosis, embolic events, and bleeding (hemorrhage)

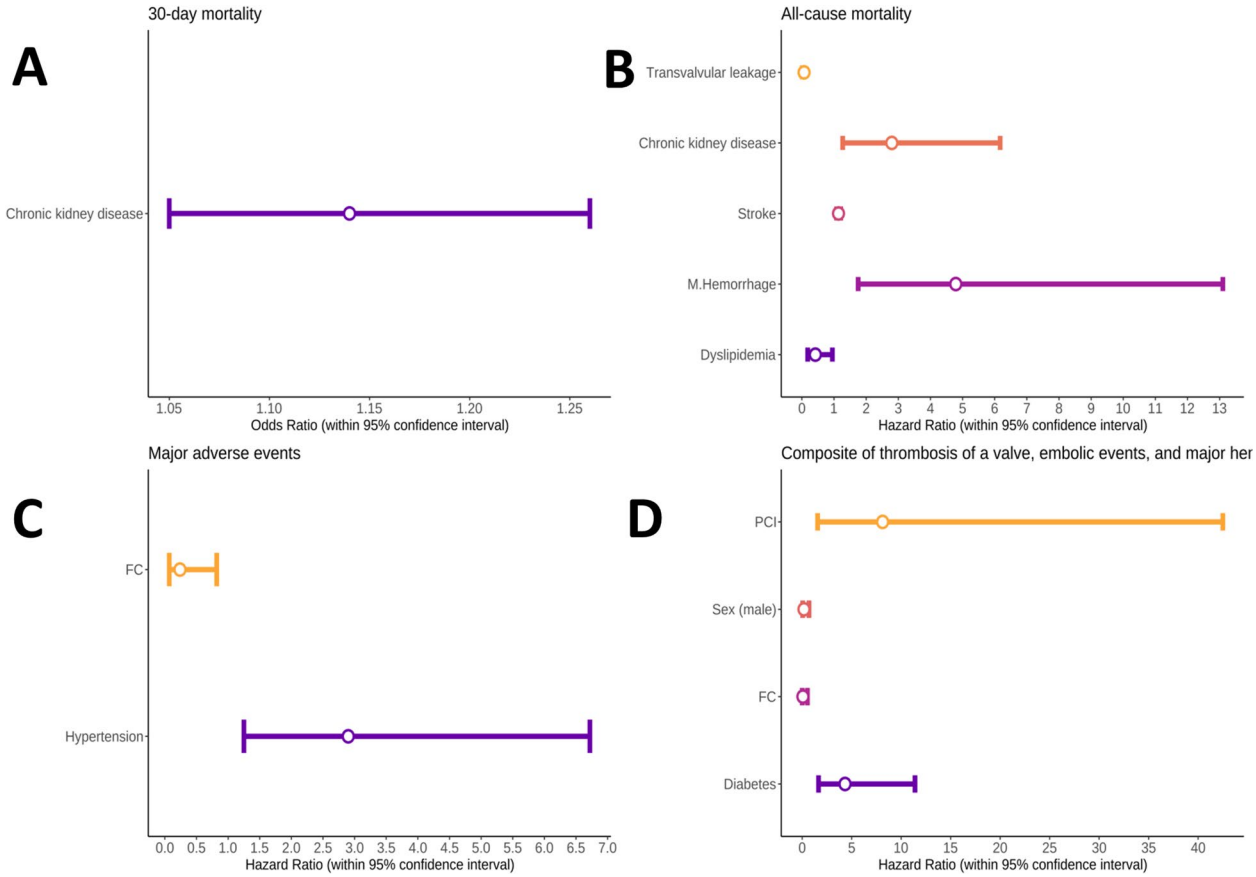

Fig. 2 The images present forest plots of multivariable analysis of study outcomes. FC; Functional class, PCI; Percutaneous coronary intervention

This study aimed to evaluate the short- and mid-term outcomes of first and second redo SVR of previously replaced valves. While numerous studies examine redo SVR, direct comparison is challenging due to the heterogeneous nature of study populations. This limitation will be acknowledged when discussing our findings.

We used BMA to address the limitation of the number of events while selecting effective predictors. Unlike traditional regression, which relies on a single model specification, BMA accounts for model uncertainty by averaging across multiple models weighted by their posterior probabilities. This approach enhances predictor selection by mitigating overfitting and improving robustness. [23].

BMA reinforces findings when predictors show high posterior inclusion probabilities, confirming their stability across models. Conversely, it challenges traditional regression results when predictors exhibit low inclusion probabilities, suggesting weaker or less reliable associations. By incorporating BMA, we ensure that our results are not overly dependent on a single model, strengthening the reliability of our conclusions despite the limited number of events [23].

Our study demonstrated a 9.3% 30-day mortality rate for both first and second redo SVR, with most mortalities taking place before hospital discharge. Early mortality rates reported within the last decade have ranged from 0% to 12.5% (0–9.5% for AVR and 5.3–12.5% for MVR). [13–15, 24–33]. Notably, most of our patients underwent first or second redo MVR, indicating that our results are consistent with those previously reported in the literature [13–15, 24–33]. In addition, early mortality after MV surgery in patients with a history of previous cardiac surgery was reported to be up to 10.9%. [34–36] Also, in a study early mortality in patients with a history of cardiac surgery after the first valve surgery was 8.6%, and after the second valve surgery was 11.2% [37]. In another study, patients with a history of cardiac surgery underwent second cardiac surgery while 70% of them underwent valve surgery. The early mortality of valve surgery was 13.6%. [38]. The early mortality for second redo MVR and second

redo AVR has been reported as 10% and 22.7%, respectively [39].

The existing literature has recognized several risk factors associated with early mortality, including lung disease, non-elective surgery, cardiopulmonary bypass time, concomitant coronary artery bypass surgery, creatinine levels, female sex, cardiogenic shock, severe tricuspid regurgitation, and functional class [20, 25, 27, 29]. In our study, chronic kidney disease emerged as a significant predictor of 30-day mortality. This finding is helpful for the risk stratification of patients before surgery and during discussions with patients and their families. Also, clinicians should optimize renal function before surgery by controlling risk factors such as hypertension and diabetes, avoiding nephrotoxic drug administration, and hypotension and closely monitoring renal function, fluid, and electrolytes.

The one-year survival rate in our study was 86%, which aligns with other studies reporting one-year survival rates after redo SVR ranging from 86 to 94% (94% for AVR and 86% for MVR) [15, 25, 33]. In a study, the 1-year survival rate in patients who had undergone MV surgery after cardiac surgery was reported as 84.4%, and in another study, it was 88% for patients with redo mitral valve surgery [35, 36]. A study reported that the 1-year survival in patients who underwent redo cardiac surgeries, most of them valve surgeries, was 78.8% [38].

Our study demonstrated a five-year survival rate of 76%. In other studies, five-year survival rates following redo SVR have been reported to be between 63 and 86% (74%–86% for AVR and 72–68% for MVR). [14, 15, 25, 27, 30, 33] The 5-year survival of mitral valve surgery after a previous cardiac surgery was reported as 86.3%, and in the other study, it was reported as 79% for patients with redo mitral valve surgery. [35, 36]. Therefore our results are consistent with the mid-range of previously published data.

Multiple factors have been identified as influencing survival outcomes in these cases, such as age, female sex, functional capacity, diabetes, chronic kidney disease, coronary artery disease, peripheral vascular disease, creatinine levels, dehiscence, additional valve replacement, right ventricular systolic pressure, high-grade aortic valve regurgitation, and elevated Society of Thoracic Surgeons scores [23, 25, 27, 30]. Our study revealed distinctive independent predictors of survival, including a history of major bleeding, stroke, and chronic kidney disease. These factors may indicate heightened risk due to bleeding tendencies, embolic events, and the multifaceted cumulative impact of various adverse factors, respectively. A history of major bleeding implies that meticulous observation, control of anticoagulant status, and patient education regarding anticoagulants are required. A history of stroke points to an increased probability of recurrent stroke and better management of stroke risk factors such as hypertension is needed. The presence of chronic kidney disease should be alarming for clinicians for close follow-up of renal function, meticulous administration of drugs and dose adjustment, and better management of chronic kidney disease progression. We observed a protective effect of dyslipidemia on mid-term survival rates, which could potentially be explained by the use of statins in all patients with dyslipidemia in our study population. The effect of statin on the survival of patients who have undergone valvular surgery was previously presented. [40] Additionally, transvalvular leakage in biological prostheses appeared to have a protective effect, possibly due to increased vigilance from patients and physicians upon detection of leakage. This heightened awareness may lead to more attentive medical care, closer adherence to treatment guidelines, and timely recognition of warning signs and symptoms. In addition, the possibility of selection bias should be considered. This means that patients with bioprosthetic transvalvular leakage had more overall health. However, our finding contradicts the current data and we could not provide scientific reasoning. Prior studies have documented the cumulative incidences of TEH and stroke at 15 years post-valve replacement, with ranges of 11.5–14.9% and 8.6–14.0%, respectively, for mechanical prosthetic valves, and 6.6–9.0% and 6.8–9.1%, respectively, for bioprosthetic valves [7, 41, 42]. Moreover, the incidence of valve thrombosis has been reported to occur at a rate of 0.1%–5.7% per patient-year [7]. Our findings chime with these studies despite the shorter follow-up time in our study. We identified diabetes, female sex, history of percutaneous coronary intervention, and NYHA functional classes I and II as independent predictors of TEH. Diabetes is known to induce a prothrombotic state [4, 43], which may account for our observations. Patients with a history of percutaneous coronary intervention may have an increased risk due to prolonged exposure to antiplatelet agents and potential comorbidities related to cerebrovascular events. Patients with higher NYHA functional classes may have received more intensive medical care prior to valve replacement, including increased monitoring, medication management, and symptom evaluation. This intensified attention could potentially contribute to better outcomes in this patient group. The risk of TEH in women following valve replacement is higher than that in men. Time in the therapeutic range serves as a marker of international normalized ratio stability, reflecting the patient's adherence, absorption, and metabolism of warfarin. Studies have shown that time in the therapeutic range is typically lower in women than in men, which may contribute to the observed differences in bleeding risk [44, 45]. These

findings imply that more careful management of diabetes and its complications and regulation of anticoagulant dose in this subset of patients is required. In addition, the careful regulation of anticoagulant doses in women and patients with a history of percutaneous coronary intervention is required. Also, patients with NYHA functional classes I and II need special attention because they are susceptible to atrial arrhythmias and the progression of heart failure, which are predisposing factors for embolic events.

Hypertension emerged as an independent predictor of MAE in our study. This finding may be attributed to the association between hypertension and various cardiovascular risk factors, such as age, systolic and diastolic dysfunction, cerebrovascular events, pulmonary hypertension, and kidney diseases. In our study, hypertension appears to serve as a surrogate marker for these underlying factors. This finding notifies the importance of rigorous hypertension management in these patients and servers for risk stratification of patients. We also observed a protective effect of preoperative functional capacity class, which was previously discussed.

Reoperation, a component of MAE, has been reported to occur at rates of 5.0%–6.9% and 11.1%–19.9% at 15 years for mechanical prosthetic valves and bioprosthetic valves, respectively [7, 41, 42]. In our study, we observed a reoperation rate of 3%, concordant with previous findings when considering the shorter follow-up period in our study. Nonstructural valve dysfunction including paravalvular leakage, patient-prosthesis mismatch, and pannus formation. We regarded the correlation between cigarette smoking and nonstructural valve dysfunction as coincidental because most of the components of this composite are anatomical factors.

One study demonstrated that more years in practice were associated with less risk-adjusted mortality among cardiac surgeons involved in valve surgeries in the first decade of practice. In addition, it presented that lower yearly case volume was associated with more risk-adjusted mortality. [46] These findings were complementary to previously presented research [47] and compatible with the results regarding redo cardiac surgery. [48].

In addition, it has been revealed that high-volume cardiac valve centers had lower risk-adjusted mortality [49] and the institutional experience effect on outcomes of patients with redo cardiac surgeries emphasized by others [50].

Our study's median number of surgeon years in practice was 10 years, which indicated that our cardiac surgeons'experience was relatively acceptable. Also, the median surgeon's annual case volume in our study was comparable to that of late-career cardiac surgeons or high-volume cardiac valve centers.

The results of valve surgery in patients undergoing three valve replacements, as well as in those receiving concomitant aortic and mitral valve replacements and coronary artery bypass surgery, have been previously presented [51, 52]. Our institutional results fall within the range of previously published data, highlighting our center's experience in the surgical management of patients requiring valve surgery. Furthermore, our center qualifies as a high-volume valve surgical institution [49, 50].

Our study offers valuable insights into the short- and midterm prognosis of redo SVR, which may aid clinicians in making informed decisions for patient management and consultation. Moreover, our results may contribute to the development of targeted care strategies to minimize potential complications in this patient group. Additionally, identifying independent factors associated with adverse events is beneficial, as addressing detrimental factors and enhancing alleviating factors may lead to better outcomes. Furthermore, the presence of risk factors for adverse outcomes highlights the need for medical care services to deliver targeted and meticulous care for these patients.

Study limitations

Several limitations exist within our study. Firstly, the retrospective design and single-center setting may introduce potential biases and limit generalizability. However, the age of our patients was younger than in some similar studies due to the prevalence of rheumatic valvular disease in our country. In addition, the results of this study are invaluable for physicians in developing countries who encounter rheumatic valvular disease and informative for physicians in developed countries when they compare the results of studies in developing and developed countries or when they are exposed to immigrants from developing countries. Also, because our study was a single-center one it may suffer from selection bias of patients, possible differences in qualities of presented medical services, local medical protocols, cultural factors, and expertise of physicians and medical personnel.

Secondly, the small sample size may impact the statistical power of our analyses. The relatively short follow-up period is another limitation, as it may not capture long-term outcomes effectively. Additionally, our study did not collect certain patient data that could have influenced our results.

Our study's distinct population, which focused exclusively on the replacement of previously replaced valves, poses challenges when making direct comparisons with other studies with broader redo SVR definitions. Some patients in our study underwent a second redo SVR, which could further impact outcomes. The inhomogeneity in the indications for redo SVR also serves as

a limitation, as this diversity may affect the observed results. Finally, concurrent surgeries and the variety of surgical techniques employed could have also impacted our findings, warranting further investigation to account for these potential confounding factors.

Conclusions

Our study demonstrates that the short- and mid-term outcomes of redo SVR are similar, establishing its feasibility as a treatment choice, particularly for patients without risk factors for mortality and adverse events. Furthermore, we have recognized potential risk factors linked to poor outcomes, which could help guide patient selection and inform tailored management approaches for optimizing outcomes in this patient population.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s40001-025-02563-x.

Additional file 1

Acknowledgements
Not applicable.

Author contributions
A.H., R.M., and P.S. contributed to Conception A.H., R.M., P.S., N.O., M.M., J.B., A.V., A.J., M.P. contributed to Work design A.H., R.M., P.S., N.O., M.M., J.B., A.V., A.J., M.P. contributed to Data acquisition A.V., A.J. Contributed to Analysis A.H., R.M., P.S., N.O., M.M., J.B., A.V., A.J., M.P. Contributed to Interpretation of data A.H., R.M., P.S., N.O., M.M., J.B., A.V., A.J., M.P. Contributed to Drafting of the manuscript: A.H., R.M., P.S., N.O., M.M., J.B., A.V., A.J., Contributed to revision of the manuscript A.H., R.M., P.S., N.O., M.M., J.B., A.V., A.J., M.P.

Funding
Not applicable.

Data availability
The data sets analyzed in the current study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate
The research proposal was approved by the institutional review board (IR.TUMS.THC.REC.1401.005) following the 1964 Declaration of Helsinki and its later amendments. Written informed consent was obtained from the study population.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Author details
[1]Cardiology Department, Tehran Heart Center, School of Medicine, Tehran University of Medical Sciences, Tehran, Iran. [2]Department of Biostatistics, Tehran Heart Center, Cardiovascular Diseases Research Institute, Tehran University of Medical Sciences, Tehran, Iran. [3]Department of Epidemiology and Biostatistics, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran. [4]Tehran Heart Center, Cardiovascular Diseases Research Institute, Tehran University of Medical Sciences, Tehran, Iran. [5]Cardiovascular Surgery Department, Tehran Heart Center, School of Medicine, Tehran University of Medical Sciences, Tehran, Iran. [6]Cardiovascular Anesthesiology Department, Tehran Heart Center, School of Medicine, Tehran University of Medical Sciences, Tehran, Iran.

Received: 16 December 2024 Accepted: 6 April 2025
Published online: 17 April 2025

References

1. Coffey S, Roberts-Thomson R, Brown A, Carapetis J, Chen M, Enriquez-Sarano M, Zühlke L, Prendergast BD. Global epidemiology of valvular heart disease. Nat Rev Cardiol. 2021;18(12):853–64. https://doi.org/10.1038/s41569-021-00570-z.
2. Santangelo G, Bursi F, Faggiano A, Moscardelli S, Simeoli PS, Guazzi M, Lorusso R, Carugo S, Faggiano P. The global burden of valvular heart disease: from clinical epidemiology to management. J Clin Med. 2023;12(6):2178. https://doi.org/10.3390/jcm12062178.
3. Writing Committee Members, Otto CM, Nishimura RA, Bonow RO, Carabello BA, Erwin JP 3rd, Gentile F, Jneid H, Krieger EV, Mack M, McLeod C, O'Gara PT, Rigolin VH, Sundt TM 3rd, Thompson A, Toly C, ACC/AHA Joint Committee Members, O'Gara PT, Beckman JA, Levine GN, Al-Khatib SM, Armbruster A, Birtcher KK, Ciggaroa J, Deswal A, Dixon DL, Fleisher LA, de Las Fuentes L, Gentile F, Goldberger ZD, Gorenek B, Haynes N, Hernandez AF, Hlatky MA, Joglar JA, Jones WS, Marine JE, Mark D, Palaniappan L, Piano MR, Spatz ES, Tamis-Holland J, Wijeysundera DN, Woo YJ. ACC/AHA guideline for the management of patients with valvular heart disease: a report of the American College of Cardiology/American Heart Association Joint Committee on Clinical Practice Guidelines. J Thorac Cardiovasc Surg. 2021;162(2):e183–353. https://doi.org/10.1016/j.jtcvs.2021.04.002.
4. Serban A, Dadarlat-Pop A, Achim A, Gavan D, Pepine D, Rancea R, Tomoaia R. Diagnosis of left-sided mechanical prosthetic valve thrombosis: a pictorial review. J Pers Med. 2023;13(6):967. https://doi.org/10.3390/jpm13060967.
5. Aluru JS, Barsouk A, Saginala K, Rawla P, Barsouk A. Valvular heart disease epidemiology. Med Sci (Basel). 2022;10(2):32. https://doi.org/10.3390/medsci10020032.
6. Thourani VH, Habib R, Szeto WY, Sabik JF, Romano JC, MacGillivray TE, Badhwar V. Survival after surgical aortic valve replacement in low-risk patients: a contemporary trial benchmark. Ann Thorac Surg. 2024;117(1):106–12. https://doi.org/10.1016/j.athoracsur.2023.10.006.
7. Schnittman SR, Itagaki S, Toyoda N, Adams DH, Egorova NN, Chikwe J. Survival and long-term outcomes after mitral valve replacement in patients aged 18 to 50 years. J Thorac Cardiovasc Surg. 2018;155(1):96-102.e11. https://doi.org/10.1016/j.jtcvs.2017.08.018.
8. Tariq MA, Malik MK, Uddin QS, Altaf Z, Zafar M. Minimally invasive procedure versus conventional redo sternotomy for mitral valve surgery in patients with previous cardiac surgery: a systematic review and meta-analysis. J Chest Surg. 2023;56(6):374–86. https://doi.org/10.5090/jcs.23.038.
9. Vella C, Romano V, Di Maio S, Ancona MB, Castriota F, Vassileva A, Ferri L, Bellini B, Moroni F, Russo F, Ghizzoni G, Gentile D, Palmisano A, Agricola E, Esposito A, Chieffo A, Montorfano M. Valve-in-valve transcatheter aortic valve implantation: the issues behind crossing a bioprosthesis. Cardiovasc Revasc Med. 2023;S1553–8389(23):00969–77. https://doi.org/10.1016/j.carrev.2023.12.015.
10. Di Muro FM, Cirillo C, Esposito L, Silverio A, Ferruzzi GJ, D'Elia D, Formisano C, Romei S, Vassallo MG, Di Maio M, Attisano T, Meucci F, Vecchione C, Bellino M, Galasso G. Valve-in-valve transcatheter aortic valve replacement: from pre-procedural planning to procedural scenarios and possible complications. J Clin Med. 2024;13(2):341. https://doi.org/10.3390/jcm13020341.
11. Formica F, Gallingani A, Tuttolomondo D, Hernandez-Vaquero D, D'Alessandro S, Pattuzzi C, Çelik M, Singh G, Ceccato E, Niccoli G, Lorusso R, Nicolini F. Redo surgical aortic valve replacement versus valve-in-valve transcatheter aortic valve implantation: a systematic review and reconstructed time-to-event meta-analysis. J Clin Med. 2023;12(2):541. https://doi.org/10.3390/jcm12020541.
12. Xu X, Liu H, Gu J, Li M, Shao Y. Valve-in-valve/valve-in-ring transcatheter mitral valve implantation vs redo surgical mitral valve replacement for

patients with failed bioprosthetic valves or annuloplasty rings: a systematic review and meta-analysis. Heliyon. 2023;9(5): e16078. https://doi.org/10.1016/j.heliyon.2023.e16078.
13. Kilic A, Acker MA, Gleason TG, Sultan I, Vemulapalli S, Thibault D, Ailawadi G, Badhwar V, Thourani V, Kilic A. Clinical outcomes of mitral valve reoperations in the United States: an analysis of The Society of Thoracic Surgeons National Database. Ann Thorac Surg. 2019;107(3):754–9. https://doi.org/10.1016/j.athoracsur.2018.08.083.
14. Yang B, Patel HJ, Norton EL, Debenedictus C, Farhat L, Wu X, He K, Hornsby WE, Likosky DS, Deeb GM. Aortic valve reoperation after stentless bioprosthesis: short- and long-term outcomes. Ann Thorac Surg. 2018;106(2):521–5. https://doi.org/10.1016/j.athoracsur.2018.02.073.
15. Mahboubi R, Kakavand M, Soltesz EG, Rajeswaran J, Blackstone EH, Svensson LG, Johnston DR. The decreasing risk of reoperative aortic valve replacement: implications for valve choice and transcatheter therapy. J Thorac Cardiovasc Surg. 2023;166(4):1043-1053.e7. https://doi.org/10.1016/j.jtcvs.2022.02.052.
16. Akins CW, Buckley MJ, Daggett WM, Hilgenberg AD, Vlahakes GJ, Torchiana DF, Madsen JC. Risk of reoperative valve replacement for failed mitral and aortic bioprostheses. Ann Thorac Surg. 1998;65(6):1545–51. https://doi.org/10.1016/s0003-4975(98)00301-4.
17. Borger MA, Prasongsukarn K, Armstrong S, Feindel CM, David TE. Stentless aortic valve reoperations: a surgical challenge. Ann Thorac Surg. 2007;84(3):737–43. https://doi.org/10.1016/j.athoracsur.2007.04.061.
18. LaPar DJ, Yang Z, Stukenborg GJ, Peeler BB, Kern JA, Kron IL, Ailawadi G. Outcomes of reoperative aortic valve replacement after previous sternotomy. J Thorac Cardiovasc Surg. 2010;139(2):263–72. https://doi.org/10.1016/j.jtcvs.2009.09.006.
19. Balsam LB, Grossi EA, Greenhouse DG, Ursomanno P, Deanda A, Ribakove GH, Culliford AT, Galloway AC. Reoperative valve surgery in the elderly: predictors of risk and long-term survival. Ann Thorac Surg. 2010;90(4):1195–200. https://doi.org/10.1016/j.athoracsur.2010.04.057.
20. Stulak JM, Tchantchaleishvili V, Daly RC, Eleid MF, Greason KL, Dearani JA, Joyce LD, Pochettino A, Schaff HV, Maltais S. Conventional redo biological valve replacement over 20 years: Surgical benchmarks should guide patient selection for transcatheter valve-in-valve therapy. J Thorac Cardiovasc Surg. 2018;156(4):1380-1390.e1. https://doi.org/10.1016/j.jtcvs.2018.03.176.
21. Ejiofor JI, Ramirez-Del Val F, Nohria A, Norman A, McGurk S, Aranki SF, Shekar P, Cohn LH, Kaneko T. The risk of reoperative cardiac surgery in radiation-induced valvular disease. J Thorac Cardiovasc Surg. 2017;154(6):1883–95. https://doi.org/10.1016/j.jtcvs.2017.07.033.
22. Akins CW, Miller DC, Turina MI, Kouchoukos NT, Blackstone EH, Grunkemeier GL, Takkenberg JJ, David TE, Butchart EG, Adams DH, Shahian DM. Guidelines for reporting mortality and morbidity after cardiac valve interventions. Ann Thorac Surg. 2008;85(4):1490–5. https://doi.org/10.1016/j.athoracsur.2007.12.082.
23. Hoeting JA, Madigan D, Raftery AE, Volinsky CT. Bayesian model averaging: a tutorial. Stat Sci. 1999;14(4):382–417. https://doi.org/10.1214/ss/1009212519.
24. Joshi Y, Achouh P, Menasché P, Fabiani JN, Berrebi A, Carpentier A, Latremouille C, Jouan J. Multiple reoperations on the aortic valve: outcomes and implications for future potential valve-in-valve strategy. Eur J Cardiothorac Surg. 2018;53(6):1251–7. https://doi.org/10.1093/ejcts/ezx469.
25. Kilic A, Helmers MR, Han JJ, Kanade R, Acker MA, Hargrove WC, Atluri P. Redo mitral valve surgery following prior mitral valve repair. J Card Surg. 2018;33(12):772–7. https://doi.org/10.1111/jocs.13944.
26. Park PW, Park B, Jeong DS, Sung K, Kim WS, Lee YT, Park SW. Clinical outcomes of repeat aortic valve replacement for subaortic pannus in mechanical aortic valve. Circ J. 2018;82(10):2535–41. https://doi.org/10.1253/circj.CJ-18-0352.
27. François K, De Backer L, Martens T, Philipsen T, Van Belleghem Y, Bové T. Repeat aortic valve surgery: contemporary outcomes and risk stratification. Interact Cardiovasc Thorac Surg. 2021;32(2):213–21. https://doi.org/10.1093/icvts/ivaa257.
28. Onorati F, Perrotti A, Reichart D, Mariscalco G, Della Ratta E, Santarpino G, Salsano A, Rubino A, Biancari F, Gatti G, Beghi C, De Feo M, Mignosa C, Pappalardo A, Fischlein T, Chocron S, Detter C, Santini F, Faggian G. Surgical factors and complications affecting hospital outcome in redo mitral surgery: insights from a multicentre experience. Eur J Cardiothorac Surg. 2016;49(5):e127–33. https://doi.org/10.1093/ejcts/ezw048.
29. Mehaffey HJ, Hawkins RB, Schubert S, Fonner C, Yarboro LT, Quader M, Speir A, Rich J, Kron IL, Ailawadi G. Contemporary outcomes in reoperative mitral valve surgery. Heart. 2018;104(8):652–6. https://doi.org/10.1136/heartjnl-2017-312047.
30. Naji P, Griffin BP, Sabik JF, Kusunose K, Asfahan F, Popovic ZB, Rodriguez LL, Lytle BW, Grimm RA, Svensson LG, Desai MY. Characteristics and outcomes of patients with severe bioprosthetic aortic valve stenosis undergoing redo surgical aortic valve replacement. Circulation. 2015;132(21):1953–60. https://doi.org/10.1161/CIRCULATIONAHA.115.015939.
31. Narayan P, Dimagli A, Fudulu DP, Sinha S, Dong T, Chan J, Angelini GD. Risk factors and outcomes of reoperative surgical aortic valve replacement in the United Kingdom. Ann Thorac Surg. 2023;116(4):759–66. https://doi.org/10.1016/j.athoracsur.2022.12.045.
32. Chikwe J, Chiang YP, Egorova NN, Itagaki S, Adams DH. Survival and outcomes following bioprosthetic vs mechanical mitral valve replacement in patients aged 50 to 69 years. JAMA. 2015;313(14):1435–42. https://doi.org/10.1001/jama.2015.3164.
33. Javadikasgari H, Chemtob RA, Gillinov AM, Pettersson GB, Lowry AM, Desai MY, Svensson LG, Blackstone EH, Wierup P. Outcomes of mitral valve re-replacement for bioprosthetic structural valve deterioration. J Thorac Cardiovasc Surg. 2022;163(5):1804-1812.e5. https://doi.org/10.1016/j.jtcvs.2020.08.067.
34. Olsthoorn JR, Heuts S, Houterman S, Maessen JG, Sardari Nia P, Cardiothoracic Surgery Registration Committee of the Netherlands Heart Registration. Minimally invasive approach compared to resternotomy for mitral valve surgery in patients with prior cardiac surgery: retrospective multicentre study based on the Netherlands Heart Registration. Eur J Cardiothorac Surg. 2022;62:420. https://doi.org/10.1093/ejcts/ezac420.
35. Hamandi M, Squiers JJ, Lanfear AT, Banwait JK, Meidan TG, Smith RL, Hutcheson K, DiMaio JM, Mack MJ, George TJ, Ryan WH. Minimally invasive mitral valve surgery after previous sternotomy: a propensity-matched analysis. J Card Surg. 2021;36:3177–83. https://doi.org/10.1111/jocs.15711.
36. Jobeir BA, De Vol AE, Alanazi ZM, Galzerano D, Jobeir AA, Alsanei AM, Alamro B, Alamri M, AlHalees ZY, Khaliel FH. Outcome of patient undergoing redo mitral valve surgery with incidence rate of mitral valve infective endocarditis. J Cardiothorac Surg. 2024;19:581. https://doi.org/10.1186/s13019-024-03063-5.
37. Tatsuishi W, Kumamaru H, Abe T, Nakano K, Miyata H, Motomura N. Postoperative outcomes of valve reoperation are associated with the number of previous cardiac operations. Gen Thorac Cardiovasc Surg. 2022;70:939–46. https://doi.org/10.1007/s11748-022-01828-0.
38. Calvelli H, Kashem MA, Hanna K, Azuma M, Cheng K, Raman R, Kehara H, Toyoda Y. Risk of mortality in patients requiring reoperative open-heart surgery. Surgery. 2025;178: 108848. https://doi.org/10.1016/j.surg.2024.09.010.
39. Rupprecht L, Schopka S, Keyser A, Lunz D, Sossalla S, Hilker M, Schmid C. 25 Years' experience with redo operations in cardiac surgery-third-time sternotomy procedures. Thorac Cardiovasc Surg. 2022;70:377–83. https://doi.org/10.1055/s-0040-1719157.
40. Fedoruk LM, Wang H, Conaway MR, Kron IL, Johnston KC. Statin therapy improves outcomes after valvular heart surgery. Ann Thorac Surg. 2008;85(5):1521–5. https://doi.org/10.1016/j.athoracsur.2008.01.078.
41. Kindzelski BA, Bakaeen FG, Tong MZ, Roselli EE, Soltesz EG, Johnston DR, Wierup P, Pettersson GB, Houghtaling PL, Blackstone EH, Gillinov AM, Svensson LG, Cleveland Clinic Collaboration on Cardiac Reoperations Working Group Collaborators. Modern practice and outcomes of reoperative cardiac surgery. J Thorac Cardiovasc Surg. 2022;164(6):1755–66. https://doi.org/10.1016/j.jtcvs.2021.01.028.
42. Chiang YP, Chikwe J, Moskowitz AJ, Itagaki S, Adams DH, Egorova NN. Survival and long-term outcomes following bioprosthetic vs mechanical aortic valve replacement in patients aged 50 to 69 years. JAMA. 2014;312(13):1323–9. https://doi.org/10.1001/jama.2014.12679.
43. Li X, Weber NC, Cohn DM, Hollmann MW, DeVries JH, Hermanides J, Preckel B. Effects of hyperglycemia and diabetes mellitus on coagulation and hemostasis. J Clin Med. 2021;10(11):2419. https://doi.org/10.3390/jcm10112419.
44. Avarello I, Bianchi S, Toschi V, Zighetti ML, Faioni EM. Time in therapeutic range is lower in women than in men and is not explained by differences

in age or comorbidity. Thromb Res. 2021;203:18–21. https://doi.org/10.1016/j.thromres.2021.04.011.
45. Erba N, Tosetto A, Abdallah SA, Langer M, Giovanella E, Lentini S, Masini F, Mocini A, Portella G, Salvati AC, Squizzato A, Testa S, Lip GYH, Poli D. Association of sex with major bleeding risks in sub-Saharian anticoagulated patients with mechanical heart valves: a cohort study from the Khartoum emergency salam centre. Int J Cardiol. 2024;394: 131398. https://doi.org/10.1016/j.ijcard.2023.131398.
46. Weininger G, Mori M, Brooks C 2nd, Shang M, Faggion Vinholo T, Zhang Y, Assi R, Geirsson A, Vallabhajosyula P. Association between cardiac surgeons' number of years in practice and surgical outcomes in New York cardiac centers. JAMA Netw Open. 2020;3(11): e2023671. https://doi.org/10.1001/jamanetworkopen.2020.23671.
47. Burt BM, ElBardissi AW, Huckman RS, Cohn LH, Cevasco MW, Rawn JD, Aranki SF, Byrne JG. Influence of experience and the surgical learning curve on long-term patient outcomes in cardiac surgery. J Thorac Cardiovasc Surg. 2015;150(5):1061–8. https://doi.org/10.1016/j.jtcvs.2015.07.068.
48. Moon MR, Henn MC, Maniar HS, Pasque MK, Melby SJ, Kachroo P, Masood MF, Itoh A, Kotkar KD, Munfakh NA, Damiano RJ Jr. Impact of surgical experience on operative mortality after reoperative cardiac surgery. Ann Thorac Surg. 2020;110(6):1909–16. https://doi.org/10.1016/j.athoracsur.2020.04.077.
49. Gonzalez AA, Dimick JB, Birkmeyer JD, Ghaferi AA. Understanding the volume-outcome effect in cardiovascular surgery: the role of failure to rescue. JAMA Surg. 2014;149(2):119–23. https://doi.org/10.1001/jamasurg.2013.3649.
50. Marin-Cuartas M, de Waha S, Saeed D, Misfeld M, Kiefer P, Borger MA. Considerations for reoperative heart valve surgery. Struct Heart. 2022;7(1): 100098. https://doi.org/10.1016/j.shj.2022.100098.
51. Davarpasand T, Hosseinsabet A. Triple valve replacement for rheumatic heart disease: short- and mid-term survival in modern era. Interact Cardiovasc Thorac Surg. 2015;20(3):359–64. https://doi.org/10.1093/icvts/ivu400.
52. Davarpasand T, Hosseinsabet A, Jalali A. Concomitant coronary artery bypass graft and aortic and mitral valve replacement for rheumatic heart disease: short- and mid-term outcomes. Interact Cardiovasc Thorac Surg. 2015;21(3):322–8. https://doi.org/10.1093/icvts/ivv132.

Publisher's Note