Impact of Mitral Valve Repair Case Volume on Postoperative Mortality

— A Nationwide Korean Cohort Study —

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Background: Although mitral valve repair is recommended over replacement due to better outcomes, repair rates vary significantly among centers. This study examined the effect of institutional mitral valve repair volume on postoperative mortality.

Methods and Results: All cases of adult mitral valve repair performed in Korea between 2009 and 2016 were analyzed. The association between case volume and 1-year mortality was analyzed after categorizing centers according to the number of mitral valve repairs performed as low-, medium-, or high-volume centers (<20, 20–40, and >40 cases/year, respectively). The effect of case volume on cumulative all-cause mortality was also assessed. In all, 6,041 mitral valve repairs were performed in 86 centers. The 1-year mortality in low-, medium-, and high-volume centers was 10.1%, 8.7%, and 4.7%, respectively. Low- and medium-volume centers had increased risk of 1-year mortality compared with high-volume centers, with odds ratios of 2.80 (95% confidence interval [CI] 2.15–3.64; $P<0.001$) and 2.66 (95% CI 1.94–3.64; $P<0.001$), respectively. The risk of cumulative all-cause mortality was also worse in low- and medium-volume centers, with hazard ratios of 1.96 (95% CI 1.68–2.29; $P<0.001$) and 1.77 (95% CI 1.47–2.12; $P<0.001$), respectively.

Conclusions: Lower institutional case volume was associated with higher mortality after mitral valve repair. A minimum volume standard may be required for hospitals performing mitral valve repair to guarantee adequate outcome.

Key Words: Case volume; Mitral valve repair; Outcomes

Mitral valve (MV) surgery is the treatment of choice for patients with symptomatic primary mitral regurgitation,^{1,2} and the surgical volume is rapidly increasing.³ Due to advances in evaluation tools and technology, mitral regurgitation patients who are asymptomatic but have poor predicted prognosis are identified early and recommended to undergo surgical intervention.^{4–7} Lower operative mortality, left ventricular function preservation, and freedom from prosthesis-related complications are proposed advantages of MV repair over MV replacement.⁸ Surgeons and hospitals with a higher volume of MV procedures have a greater proportion of MV repairs than MV replacements, which may, in turn, explain better outcomes associated with higher case volume.⁹ Accordingly, guidelines from major professional societies uniformly suggest that MV repair should be pre-

ferred to MV replacement when the results are expected to be successful and durable.^{2,4,5}

However, the proportion of MV repair to MV replacement varies considerably across surgeons and hospitals,¹⁰ implying that patients who undergo MV replacement in one hospital may receive MV repair in another. Proposed explanations seem to stem from the complexity of the MV repair procedure, which requires not only skilled cardiac surgeons, but also experienced cardiologists and/or cardiac anesthesiologists with expertise in identifying suitable patients for repair, as well as accurate perioperative assessment, including prognostication of residual regurgitation immediately after repair.¹¹

In this regard, the cumulative MV repair experience of cardiac surgery centers may contribute significantly to patient outcome after MV repair. Furthermore, a previous

Received December 16, 2019; revised manuscript received May 11, 2020; accepted June 8, 2020; J-STAGE Advance Publication released online August 1, 2020 Time for primary review: 57 days

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ISSN-1346-9843

	Low-volume centers (<20 cases/year)	Medium-volume centers (20–40 cases/year)	High-volume centers (>40 cases/year)	P-value
No. patients	1,728	1,067	3,246	
Age (years)	57±14	60±14	59±13	<0.001
Female sex	729 (42)	473 (44)	1,506 (46)	0.017
Hypertension	1,069 (62)	639 (60)	2,104 (65)	0.007
Diabetes	215 (12)	133 (12)	319 (10)	0.005
Hyperlipidemia	316 (18)	206 (19)	596 (18)	0.758
Extracardiac arteriopathy	195 (11)	128 (12)	285 (9)	0.001
Renal impairment	20 (1)	20 (2)	43 (1)	0.269
Chronic lung disease	726 (42)	489 (46)	1,288 (40)	0.002
Pulmonary hypertension	14 (1)	11 (1)	77 (2)	<0.001
Angina pectoris	516 (30)	285 (27)	937 (29)	0.199
Recent MI ^a	43 (2)	24 (2)	76 (2)	0.912
History of PCI	33 (2)	19 (2)	46 (1)	0.383
Congestive heart failure	548 (32)	346 (32)	1,008 (31)	0.684
Atrial fibrillation	449 (26)	317 (30)	1,049 (32)	<0.001
Atrioventricular block	11 (1)	6 (1)	15 (1)	0.713
History of sustained VF/VT	13 (1)	10 (1)	21 (1)	0.620
Rheumatic MV pathology	224 (13)	135 (13)	612 (19)	<0.001
Infective endocarditis	138 (8)	75 (7)	215 (7)	0.203
Concomitant tricuspid valve repair	393 (23)	256 (24)	916 (28)	<0.001
Urgent or emergent surgery	60 (3)	11 (1)	41 (1)	<0.001
Perioperative RBC transfusion (units)				<0.001
0–2	871 (50)	632 (59)	1,665 (51)	
3–5	687 (40)	365 (34)	1,252 (39)	
≥6	170 (10)	70 (7)	329 (10)	

Unless indicated otherwise, data are presented as n (%) or mean±SD. ^aDiagnosed within 3 months before surgery. MI, myocardial infarction; MV, mitral valve; PCI, percutaneous coronary intervention; RBC, red blood cell; VF/VT, ventricular fibrillation or ventricular tachycardia.

Figure 1. Scatterplot showing the association between case volume and 1-year mortality after mitral valve repair in low-, medium-, and high-volume centers (<20, 20–40, and >40 cases/year, respectively).

Table 2. Logistic Regression for the Risk of 1-Year Mortality After MV Repair

	Unadjusted		Adjusted	
	OR (95% CI)	P-value	OR (95% CI)	P-value
Case volume strata				
High (>40 cases/year)	Reference		Reference	
Medium (20–40 cases/year)	1.93 (1.48–2.52)	<0.001	2.66 (1.94–3.64)	<0.001
Low (<20 cases/year)	2.28 (1.82–2.85)	<0.001	2.80 (2.15–3.64)	<0.001
Age (years)				
18–49	Reference		Reference	
50–59	2.69 (1.73–4.18)	<0.001	2.02 (1.25–3.25)	0.004
60–69	3.91 (2.58–5.93)	<0.001	2.41 (1.53–3.82)	<0.001
70–79	9.41 (6.31–14.03)	<0.001	4.80 (3.05–7.56)	<0.001
≥80	14.26 (8.42–24.14)	<0.001	8.85 (4.86–16.14)	<0.001
Female sex	1.22 (1.00–1.49)	0.050	0.87 (0.69–1.10)	0.253
Hypertension	1.90 (1.51–2.4)	<0.001	1.03 (0.78–1.38)	0.818
Diabetes	2.20 (1.79–2.96)	<0.001	1.20 (0.89–1.63)	0.232
Hyperlipidemia	1.92 (1.54–2.39)	<0.001	1.06 (0.80–1.39)	0.686
Extracardiac arteriopathy	2.30 (1.78–2.98)	<0.001	1.49 (1.10–2.02)	0.011
Renal impairment	7.63 (4.80–12.11)	<0.001	2.27 (1.26–4.09)	0.007
Chronic lung disease	1.57 (1.29–1.91)	<0.001	1.07 (0.85–1.36)	0.554
Pulmonary hypertension	1.14 (0.55–2.36)	0.727	1.17 (0.49–2.75)	0.725
Angina pectoris	2.05 (1.68–2.51)	<0.001	1.32 (1.03–1.69)	0.029
Recent MI ^A	2.37 (1.47–3.80)	<0.001	1.46 (0.82–2.61)	0.195
History of PCI	3.78 (2.31–6.19)	<0.001	0.95 (0.51–1.77)	0.862
Congestive heart failure	1.66 (1.35–2.02)	<0.001	1.11 (0.86–1.43)	0.432
Atrial fibrillation	1.52 (1.24–1.86)	<0.001	1.19 (0.91–1.55)	0.205
Atrioventricular block	1.38 (0.42–4.56)	0.592	1.00 (0.23–4.35)	0.999
History of sustained VF/VT	1.34 (0.48–3.76)	0.580	1.42 (0.46–4.35)	0.541
Rheumatic MV pathology	1.14 (0.88–1.48)	0.313	1.00 (0.74–1.35)	0.999
Infective endocarditis	1.46 (1.04–2.05)	0.029	1.47 (0.97–2.22)	0.072
Concomitant tricuspid valve repair	1.45 (1.17–1.79)	<0.001	1.08 (0.82–1.41)	0.577
Urgent or emergent surgery	3.00 (1.83–4.91)	<0.001	1.36 (0.76–2.45)	0.301
Perioperative RBC transfusion (units)				
0–2	Reference		Reference	
3–5	3.56 (2.62–4.82)	<0.001	2.88 (2.1–3.95)	<0.001
≥6	30.99 (22.81–42.12)	<0.001	24.07 (17.2–33.68)	<0.001
Surgery year	1.00 (0.96–1.04)	0.941	0.97 (0.92–1.02)	0.286

^ADiagnosed within 3 months before surgery. CI, confidence interval; OR, odds ratio. Other abbreviations as in Table 1.

study suggested that mortality after MV repair may not be associated with MV procedure volume.¹² It remains unclear whether ‘repair only’ volume is related to mortality after MV repair. To test this hypothesis, we performed a nationwide cohort study to evaluate the effect of pure MV repair volume of centers on postoperative mortality.

Methods

The present study was a retrospective, nationwide Korean cohort study. The study protocol was approved by the Institutional Review Board of Seoul National University Hospital (IRB number 1803-058-928). The need for individual patient consent was waived by the review board.

Study Population and Data Collection

All data were obtained from the National Health Insurance Service (NHIS) database. The NHIS provides healthcare insurance coverage to the vast majority (>97%) of residents in Korea.^{13,14} Adult (age ≥18 years) patients who underwent

MV repair between January 2009 and December 2016 in Korea were identified using the billing code for MV repair (O1782). The approach method (median sternotomy or thoracotomy) for MV repair was not specified. Patients who underwent open mitral commissurotomy for mitral stenosis or concomitant cardiac surgical procedures, with the exception of tricuspid valve repair, were excluded from the study. Patient characteristics and preoperative comorbidities were identified using the International Classifications of Diseases, 10th revision (ICD-10) codes. Perioperative transfusion data were also collected using billing codes for transfusion (Table 1). Data regarding in-hospital, 1-year, and cumulative all-cause mortality, as well as reoperation (repair or replacement) on the MV were also obtained.

Definition of Case Volume

Institutional case volume was defined as the mean number of MV repairs performed per year during the study period. Centers were categorized into 3 groups according to the case volume: high volume (>40 cases/year), medium volume

Table 3. Logistic Regression for In-Hospital Mortality After MV Repair

	Unadjusted		Adjusted	
	OR (95% CI)	P-value	OR (95% CI)	P-value
Case volume strata				
High (>40 cases/year)	Reference		Reference	
Medium (20–40 cases/year)	1.56 (1.10–2.22)	0.013	2.55 (1.69–3.87)	<0.001
Low (<20 cases/year)	2.42 (1.84–3.19)	<0.001	3.22 (2.32–4.48)	<0.001
Age (years)				
18–49	Reference		Reference	
50–59	3.03 (1.72–5.33)	<0.001	2.22 (1.20–4.11)	0.011
60–69	4.32 (2.53–7.36)	<0.001	2.69 (1.48–4.87)	0.001
70–79	9.40 (5.62–15.74)	<0.001	4.58 (2.53–8.26)	<0.001
≥80	13.01 (6.67–25.40)	<0.001	7.91 (3.61–17.32)	<0.001
Female sex	1.32 (1.03–1.69)	0.026	0.96 (0.72–1.29)	0.797
Hypertension	1.74 (1.32–2.31)	<0.001	1.01 (0.71–1.45)	0.937
Diabetes	2.09 (1.53–2.86)	<0.001	0.99 (0.68–1.45)	0.970
Hyperlipidemia	1.93 (1.47–2.53)	<0.001	1.04 (0.74–1.47)	0.817
Extracardiac arteriopathy	1.99 (1.44–2.77)	<0.001	1.36 (0.92–2.02)	0.126
Renal impairment	5.91 (3.41–10.22)	<0.001	1.19 (0.61–2.35)	0.608
Chronic lung disease	1.23 (0.96–1.57)	0.104	0.83 (0.61–1.12)	0.215
Pulmonary hypertension	1.39 (0.59–3.15)	0.463	1.68 (0.60–4.70)	0.328
Angina pectoris	2.04 (1.59–2.62)	<0.001	1.35 (0.98–1.84)	0.063
Recent MI ^A	3.28 (1.97–5.46)	<0.001	2.18 (1.14–4.18)	0.018
History of PCI	4.44 (2.56–7.70)	<0.001	1.12 (0.56–2.26)	0.750
Congestive heart failure	1.33 (1.03–1.71)	0.029	0.83 (0.60–1.15)	0.273
Atrial fibrillation	1.45 (1.13–1.87)	0.004	1.26 (0.90–1.77)	0.178
Atrioventricular block	1.45 (0.35–6.11)	0.609	1.12 (0.19–6.51)	0.898
History of sustained VF/VT	1.60 (0.49–5.19)	0.437	2.14 (0.57–7.97)	0.258
Rheumatic MV pathology	1.35 (0.99–1.83)	0.055	1.19 (0.82–1.71)	0.358
Infective endocarditis	1.65 (1.11–2.46)	0.014	1.37 (0.83–2.24)	0.215
Concomitant tricuspid valve repair	1.29 (0.99–1.68)	0.061	0.90 (0.64–1.27)	0.548
Urgent or emergent surgery	4.70 (2.82–7.82)	<0.001	1.69 (0.90–3.15)	0.101
Perioperative RBC transfusion (units)				
0–2 units	Reference		Reference	
3–5 units	9.92 (5.26–18.70)	<0.001	8.23 (4.34–15.60)	<0.001
≥6 units	130.62 (70.42–242.30)	<0.001	107.51 (56.82–203.44)	<0.001
Surgery year	0.98 (0.93–1.04)	0.508	0.97 (0.91–1.04)	0.433

^ADiagnosed within 3 months before surgery. Abbreviations as in Tables 1,2.

(20–40 cases/year), and low volume (<20 cases/year).

Study Endpoints and Statistical Analysis

The primary endpoint was 1-year mortality following MV repair. Secondary endpoints included in-hospital mortality, reoperation of the MV, and cumulative all-cause mortality.

Continuous variables are presented as the mean±SD, and categorical variables are given as numbers with percentages. The Chi-squared test was used to compare categorical variables and analysis of variance (ANOVA) was used for comparison between continuous variables.

Univariable and multivariable logistic regression analyses were used to compare 1-year mortality and in-hospital mortality between the case volume strata. All variables listed in **Table 1** and year of surgery were adjusted for in the multivariable analysis. To compare the risk of reoperation on the MV between the case volume strata, Cox proportional hazards regression was performed. Cumulative survival after MV repair was calculated using the Kaplan–Meier method and compared using adjusted survival

curves and the log-rank test among the case volume strata. Cox proportional hazards regression was then performed to compare the risk of all-cause mortality according to the case volume strata. The same covariates used in the logistic regression were adjusted for in the multivariable Cox regressions. The proportional hazards assumption was tested and verified by plotting log-minus-log curves.

All statistical analyses were performed using SAS 9.4 (SAS Institute, Cary, NC, USA) and R ver. 3.4.3 (R Development Core Team, Vienna, Austria). A P-value of <0.05 was considered as statistically significant.

Results

Baseline Characteristics

In all, 6,041 MV repairs were performed in 86 centers with 1,728, 1,067, and 3,246 patients undergoing MV repair in 76 low-, 5 medium-, and 5 high-volume centers, respectively. The median number of cases per year in the low-, medium-, and high-volume centers was 2 (interquartile range [IQR]

Table 4. Cox Regression for Reoperation on the MV After MV Repair

	No. events (%)	Unadjusted		Adjusted	
		HR (95% CI)	P-value	HR (95% CI)	P-value
Case volume strata					
High (>40 cases/year)	57 (1.8)	Reference		Reference	
Medium (20–40 cases/year)	27 (2.5)	1.53 (0.97–2.41)	0.068	1.86 (1.16–2.98)	0.010
Low (<20 cases/year)	52 (3.0)	1.82 (1.25–2.63)	0.002	1.91 (1.30–2.81)	0.001
Age (years)					
18–49		Reference		Reference	
50–59		1.46 (0.94–2.26)	0.093	1.40 (0.89–2.19)	0.145
60–69		1.01 (0.63–1.60)	0.982	0.85 (0.51–1.43)	0.536
70–79		0.64 (0.36–1.13)	0.121	0.42 (0.23–0.77)	0.005
≥80		1.21 (0.99–3.38)	0.719	0.76 (0.27–2.13)	0.597
Female sex		1.17 (0.84–1.64)	0.350	1.21 (0.87–1.70)	0.251
Hypertension		0.68 (0.49–0.95)	0.025	0.71 (0.47–1.06)	0.093
Diabetes		0.65 (0.34–1.23)	0.182	0.65 (0.33–1.26)	0.197
Hyperlipidemia		1.04 (0.68–1.61)	0.853	1.21 (0.76–1.93)	0.423
Extra-cardiac arteriopathy		1.14 (0.67–1.95)	0.627	1.26 (0.71–2.24)	0.424
Renal impairment		2.74 (1.12–6.70)	0.027	1.34 (0.53–3.43)	0.538
Chronic lung disease		0.91 (0.65–1.29)	0.606	0.96 (0.66–1.39)	0.830
Pulmonary hypertension		0.42 (0.06–2.95)	0.380	0.44 (0.06–3.22)	0.417
Angina pectoris		0.92 (0.63–1.34)	0.649	1.02 (0.69–1.52)	0.925
Recent MI ^a		0.61 (0.15–2.47)	0.492	0.66 (0.15–2.99)	0.590
History of PCI		0.45 (0.06–3.22)	0.426	0.35 (0.04–2.82)	0.326
Congestive heart failure		0.90 (0.63–1.31)	0.593	0.98 (0.65–1.47)	0.913
Atrial fibrillation		1.05 (0.73–1.51)	0.799	1.07 (0.70–1.62)	0.762
Atrioventricular block		2.97 (0.75–11.81)	0.123	2.95 (0.68–12.79)	0.148
History of sustained VF/VT		1.16 (0.55–2.43)	0.703	1.36 (0.65–2.88)	0.416
Rheumatic MV pathology		1.37 (0.92–2.05)	0.121	1.25 (0.82–1.90)	0.301
Infective endocarditis		2.07 (1.26–3.39)	0.004	1.48 (0.89–2.46)	0.130
Concomitant tricuspid valve repair		1.44 (1.01–2.06)	0.045	1.50 (1.01–2.22)	0.046
Urgent or emergent surgery		1.15 (0.37–3.62)	0.812	0.45 (0.14–4.45)	0.182
Perioperative RBC transfusion (units)					
0–2		Reference		Reference	
3–5		1.68 (1.13–2.50)	0.010	1.79 (1.19–2.70)	0.005
≥6		4.83 (3.12–7.46)	<0.001	5.92 (3.76–9.31)	<0.001
Surgery year		1.04 (0.97–1.12)	0.300	1.04 (0.96–1.12)	0.339

^aDiagnosed within 3 months before surgery. Abbreviations as in Tables 1,2.

1–4), 23 (IQR 22–30), and 87 (IQR 72–97), respectively. Baseline patient characteristics are presented in **Table 1**.

1-Year Mortality

The overall 1-year mortality rate after MV repair was 7.0% (421/6,041). The 1-year mortality rates in the low-, medium-, and high-volume centers were 10.1%, 8.7%, and 4.7%, respectively. **Figure 1** shows 1-year mortality according to annual institutional case volume. Multivariate logistic regression showed that, compared with high-volume centers, 1-year mortality after MV repair was significantly higher in medium- and low-volume centers, with adjusted odds ratios (OR) of 2.66 (95% confidence interval [CI] 1.94–3.64; $P<0.001$) and 2.80 (95% CI 2.15–3.64; $P<0.001$), respectively (**Table 2**).

In-Hospital Mortality

In-hospital mortality rates after MV repair in low-, medium-, and high-volume centers were 6.9%, 4.6%, and 3.0%, respectively, with an overall in-hospital mortality rate of

4.4% (266/6,041). After adjustment, the risk of in-hospital mortality was significantly higher in low- and medium-volume than in high-volume centers (ORs 3.22 [95% CI 2.32–4.48; $P<0.001$] and 2.55 [95% CI 1.69–3.87; $P<0.001$], respectively; **Table 3**).

Reoperation on the MV After MV Repair

After initial MV repair, 136 (2.3%) patients underwent re-repair ($n=18$) or replacement ($n=118$) surgery on the repaired MV: 57 (1.8%), 27 (2.5%), and 52 (3.0%) patients in the high-, medium-, and low-volume centers, respectively. After adjustment, the risk of MV reoperation was significantly higher in low- and medium-volume centers than in high-volume centers, with adjusted hazard ratios [HRs] of 1.86 (95% CI 1.16–2.98; $P=0.010$) and 1.91 (95% CI 1.30–2.81; $P=0.001$), respectively (**Table 4**).

Cumulative All-Cause Mortality

The median duration of follow-up for cumulative all-cause mortality was 4.6 years (IQR 2.3–6.8 years). Cumulative

1-year survival probability in the low-, medium-, and high-volume centers was 0.89 (95% CI 0.88–0.91), 0.91 (95% CI 0.90–0.93), and 0.95 (95% CI 0.94–0.96), respectively, with corresponding cumulative 5-year survival probability of 0.82 (95% CI 0.80–0.84), 0.83 (95% CI 0.80–0.85), and 0.90 (0.89–0.91). The adjusted survival curves showed that survival was significantly higher for patients who underwent MV repair in high-volume centers compared with medium- and low-volume centers ($P < 0.001$; **Figure 2**). Low- and medium-volume centers were combined for the Cox regression analysis because the proportional hazards could not be assumed between the 2 groups. Cox proportional hazards regression showed that the risk of cumulative all-cause death for patients in low- or medium-volume centers was significantly higher than for patients in high-volume centers (adjusted HR 1.89; 95% CI 1.64–2.17; $P < 0.001$; **Table 5**).

Discussion

In this nationwide cohort study we found that the risk of 1-year and cumulative all-cause mortality following MV repair was significantly higher in low- (<20 cases/year) and medium-volume (20–40 cases/year) centers compared with high-volume (>40 cases/year) centers. The risk of in-hospital mortality and reoperation (re-repair or replacement) on the MV after repair was also higher in medium- and low-volume centers.

The association between lower case volume and higher mortality has been shown for various complex, high-risk surgical procedures.^{15,16} An inverse relationship between case volume and mortality has been consistently demon-

strated for complex, high-risk surgical procedures such as major cancer surgery,^{16–18} ruptured abdominal aortic aneurysm repair,¹⁹ carotid endarterectomy,²⁰ and solid organ transplantation.^{20–22} Regarding cardiac surgery, the volume–outcome relationship has been largely investigated for coronary artery bypass grafting, for which the results remain somewhat controversial.^{23–28} A few studies also examined the relationship for aortic valve or MV replacement, where higher surgeon or center volume was associated with lower postoperative mortality.^{29–32} However, the volume–outcome relationship in cardiac surgery may arguably remain controversial because it is based on a limited number of studies with modest quality and strength.³³

Several studies investigated the volume–outcome relationship for MV surgery.^{9,10,34,35} Although patient populations and study protocols vary slightly, higher surgeon or institutional MV surgery volume was significantly associated with a higher proportion of repair (vs. replacement), which may have contributed to the favorable outcome.^{9,10,35} Moreover, the American College of Cardiology/American Heart Association and the European Society of Cardiology/European Association of Cardio-Thoracic Surgery acknowledged in their guidelines that outcomes following MV repair may depend on the experience of the surgeon or the center.^{2,4,5} Previous studies have used mean annual volume of “all types” of MV surgery to define MV surgery case volume. It is doubtful whether a high case volume of MV replacement would be directly related to favorable outcomes after MV repair in an institution where the case volume for MV repair is low. The counterargument may be that MV repair, such as resection of an isolated P2 scallop prolapse, is relatively simple and technically straight-

Table 5. Cox Regression for Cumulative All-Cause Mortality After MV Repair

	Unadjusted		Adjusted	
	HR (95% CI)	P-value	HR (95% CI)	P-value
Case volume strata				
High (>40 cases/year)	Reference		Reference	
Low and medium (≤40 cases/year)	1.78 (1.56–2.04)	<0.001	1.89 (1.64–2.17)	<0.001
Age (years)				
18–49	Reference		Reference	
50–59	2.40 (1.77–3.26)	<0.001	1.94 (1.42–2.65)	<0.001
60–69	4.74 (3.59–6.25)	<0.001	3.21 (2.40–4.28)	<0.001
70–79	9.68 (7.39–12.68)	<0.001	5.95 (4.46–7.95)	<0.001
≥80	14.51 (10.15–20.75)	<0.001	9.80 (6.74–14.25)	<0.001
Female sex	1.02 (0.89–1.17)	0.774	0.74 (0.64–0.85)	<0.001
Hypertension	1.92 (1.64–2.24)	<0.001	1.04 (0.88–1.24)	0.634
Diabetes	2.43 (2.06–2.86)	<0.001	1.33 (1.12–1.58)	0.001
Hyperlipidemia	1.90 (1.64–2.21)	<0.001	1.06 (0.90–1.25)	0.475
Extracardiac arteriopathy	1.88 (1.57–2.26)	<0.001	1.17 (0.97–1.42)	0.098
Renal impairment	7.12 (5.41–9.39)	<0.001	2.94 (2.17–3.98)	<0.001
Chronic lung disease	1.51 (1.32–1.72)	<0.001	1.02 (0.89–1.17)	0.821
Pulmonary hypertension	1.11 (0.69–1.80)	0.659	0.98 (0.60–1.61)	0.948
Angina pectoris	1.76 (1.54–2.02)	<0.001	1.12 (0.96–1.29)	0.149
Recent MI ^A	2.20 (1.59–3.03)	<0.001	1.31 (0.92–1.85)	0.135
History of PCI	3.83 (2.79–5.24)	<0.001	1.34 (0.95–1.90)	0.099
Congestive heart failure	1.80 (1.57–2.06)	<0.001	1.19 (1.02–1.38)	0.026
Atrial fibrillation	1.55 (1.35–1.78)	<0.001	1.14 (0.98–1.34)	0.093
Atrioventricular block	0.95 (0.35–2.52)	0.910	0.69 (0.26–1.86)	0.464
History of sustained VF/VT	1.16 (0.55–2.43)	0.703	1.36 (0.64–2.87)	0.422
Rheumatic MV pathology	1.00 (0.84–1.19)	>0.999	0.96 (0.80–1.15)	0.675
Infective endocarditis	1.07 (0.83–1.39)	0.590	1.24 (0.95–1.63)	0.112
Concomitant tricuspid valve repair	1.59 (1.38–1.82)	<0.001	1.16 (0.99–1.36)	0.061
Urgent or emergency surgery	2.55 (1.84–3.55)	<0.001	1.62 (1.14–2.28)	0.007
Perioperative RBC transfusion (units)				
0–2	Reference		Reference	
3–5	2.53 (2.13–3.01)	<0.001	2.05 (1.72–2.45)	<0.001
≥6	11.92 (9.95–14.29)	<0.001	7.65 (6.28–9.30)	<0.001
Surgery year	1.03 (0.99–1.06)	0.113	1.00 (0.97–1.04)	0.968

^ADiagnosed within 3 months before surgery. Abbreviations as in Tables 1,2.

forward, similar to a prosthetic replacement.¹¹ However, the proportion of MV repairs (vs. replacement) varies significantly among centers,¹⁰ and the mean MV repair case volume per cardiac surgeon in the US has been reported to be <5 per year.³⁴ In addition, even repairing P2 prolapse may not always be straightforward and can be challenging due to accompanying annular calcification, a shortage of remaining tissue after leaflet resection, potential systolic anterior motion of the MV, or residual regurgitation.¹¹ Considering the uniqueness of MV repair, “repair only” volume should be considered when evaluating the volume–outcome relationship in MV repair. Of note, a previous study showed that mortality after MV repair was not associated with hospital volume of MV surgery, although the results were not adjusted.¹² To the best of our knowledge, the present analysis is the first nationwide cohort study that showed a significant inverse relationship between the pure MV repair volume of centers and postoperative mortality.

Surgeon and center volumes of 25 and 50 cases/year, respectively, were proposed as thresholds in a statement on best practices for MV repair in the UK.³⁶ In the present

study, patients who underwent MV repair in centers with an annual volume of ≥40 cases had the best outcomes, including postoperative mortality and the risk of reoperation. However, a volume threshold for optimizing MV repair outcome is yet to be established.

The number of MV repairs is increasing rapidly, with >8,000 cases performed annually in the US.³ Indications for MV repair are expanding with advances in relative fields, such as cardiac surgery, cardiology, and cardiac anesthesia.^{37,38} However, discrepancies between centers in terms of the proportion of MV repairs (vs. replacement), MV repair case volume, and subsequent outcomes persist.¹⁰ Socioeconomic and ethical issues regarding the distribution of resources and patient outcomes will require careful consideration in the future. Regionalizing the limited resources to a few high-volume centers may improve patient outcome while sacrificing medical accessibility. The optimal balance between outcome and accessibility is unclear and should be contemplated extensively.

There are several limitations to consider in this study. First, this study was retrospective and so the results only

show an association between institutional case volume and mortality after MV repair. Because all MV repairs performed during the past 8 years in Korea were included in the present study, the results show the whole picture of the current status. Second, many perioperative clinical data, such as the location and severity of the MV lesion, type of MV repair performed, left ventricular function, laboratory findings, medication history, and surgery or cardiopulmonary bypass records could not be obtained because the NHIS database lacked clinical data. In addition, the European System for Cardiac Operative Risk Evaluation (EuroSCORE) II and STS Predicted Risk of Mortality (PROM) score could not be collected, although most of the variables included in both scoring systems were adjusted for in the present study. To minimize the effects of these biases, only concrete outcomes such as mortality and surgical procedure were assessed. Third, the etiology of mitral regurgitation, particularly degenerative and ischemic mitral regurgitation, was not clearly defined using the ICD-10 codes. However, considering the relatively small proportion of patients with rheumatic MV pathology (16.1%), infective endocarditis (7.1%), and recent myocardial infarction (2.4%) and/or a history of percutaneous coronary intervention (1.6%). Most cases are likely to have a degenerative etiology of mitral regurgitation. Fourth, cause of death was not presented due to lack of data. Operative failure may have contributed to the higher chance of death following MV repair in low-volume centers considering the increased risk of in-hospital mortality and MV reoperation in these centers. In addition, differences in the capacity of institutions to cope with postoperative complications may have contributed to the different outcomes between institutions with varying case volumes.

In conclusion, institutional case volume of MV repair may be associated with 1-year mortality and cumulative all-cause mortality after MV repair. The lowest postoperative mortality was seen among patients who underwent MV repair in centers performing ≥ 40 cases of MV repair annually. These results suggest that setting a minimum center volume of MV repair may help achieve optimal patient outcomes after MV repair.

Acknowledgments

None.

Sources of Funding

This study did not receive any specific funding.

Disclosures

The authors declare that they have no conflicts of interest.

IRB Information

This study was approved by the Institutional Review Board of Seoul National University Hospital (1803-058-928).

Data Availability

The deidentified participant data cannot not be shared because the data used for this study were Korean national administrative data.

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