Re-repair of post–myocardial infarction ventricular septal rupture

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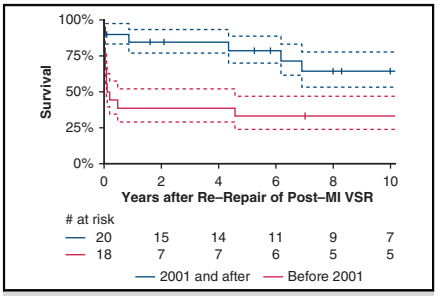
ABSTRACT

Background: Survivors of post–myocardial infarction (MI) ventricular septal rupture (VSR) repair may require reintervention if initial repairs are incomplete or fail. We assessed patients undergoing post-MI VSR re-repair.

Methods: Between January 1976 and July 2023, 38 consecutive patients underwent re-repair of post-MI VSR at Cleveland Clinic. Preoperative characteristics, operative details, and postoperative outcomes were obtained through medical records review, and patients were followed for survival.

Results: Thirty-two (84%) re-repairs were elective/urgent, and 6 (16%) were emergencies. Preoperative temporary mechanical circulatory support was used in 14 (37%), with 12 isolated intra-aortic balloon pumps. Indications for re-repair were recurrent VSR detected during postoperative surveillance (n = 25; 66%) and residual VSR after incomplete initial repair (n = 13; 34%). The median time from initial repair to re-repair was 55 days (15th/85th percentiles: 5-331 days). Two patients (5.3%) had residual or recurrent VSR after re-repair but received no intervention due to hemodynamic insignificance. Postoperative complications included sepsis (n = 7; 18%), stroke (n = 6; 16%), and new-onset dialysis (n = 6; 16%). Operative mortality was 32% (n = 12), with differences between patients who underwent surgery before January 2001 (n = 10/18; 56%) and those who did so after January 2001 (n = 2/20; 10%), as well as between patients who received preoperative temporary mechanical circulatory support (n = 8/14; 57%) and those who did not (n = 4/24; 17%).

Conclusions: Patients with failed or incomplete initial post-MI VSR repairs may be considered for re-repair, as modern-day improvements in perioperative care may be associated with more favorable outcomes. Referral to an expert tertiary center should be considered owing to the surgical complexity of re-repair. (JTCVS Techniques 2025;29:43-55)



Post-MI VSR re-repair operative mortality was lower in/after 2001 (10%) compared to before 2001 (56%).

CENTRAL MESSAGE

Patients surviving initial post–myocardial infarction ventricular septal rupture repair who present with residual or recurrent shunts requiring surgical re-repair achieve favorable postoperative outcomes in the modern era in a tertiary center.

PERSPECTIVE

Patients surviving initial post–myocardial infarction ventricular septal rupture repair may develop clinically significant residual or recurrent shunt. Therefore, it is crucial that these patients undergo routine imaging and clinical follow-up. For those presenting with clinically significant residual or recurrent shunt, surgical re-repair is safe in the modern era, but referral to expert tertiary centers should be considered.

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Abbreviations and Acronyms

ECMO = extracorporeal membrane oxygenation
IABP = intra-aortic balloon pump
MI = myocardial infarction
tMCS = temporary mechanical circulatory support
VSR = ventricular septal rupture

Following a myocardial infarction (MI), the occurrence of a ventricular septal rupture (VSR) is relatively rare but can lead to significant morbidity and mortality.[1-5] Although there is ongoing debate regarding optimal timing for intervention, the gold standard treatment for addressing a post-MI VSR remains open surgical repair.[6-8] Among patients who survive their initial repair, a subset experience either incomplete initial repair or later repair failure, resulting in shunt recurrence.[4,5,9-15] This concern is particularly pertinent for patients who undergo emergency surgical repair, in which the compromised quality of infarcted tissue may increase the risk of repair failure. Moreover, inferoposterior VSRs present additional challenges because of their morphologic complexities and associated technical repair difficulties.[9-11,13]

The recurrence of a hemodynamically significant shunt is a negative prognostic indicator, amplifying the risk for re-operation and operative mortality.[10,12,14] However, despite the clinical significance, there is currently a lack of studies characterizing the presentation and outcomes of patients who undergo re-repair following failed initial surgical post-MI VSR repair.[5] Here we present the largest single series reported to date, providing comprehensive insights into the perioperative characteristics, surgical details, and outcomes of patients presenting with residual or recurrent post-MI VSR following initial surgical repair.

METHODS

Patients and Data

From January 1976 to July 2023, 38 consecutive patients who had previously undergone surgical repair of a post-MI VSR underwent re-repair at Cleveland Clinic. The median age at re-repair was 64 years (15th-85th percentile, 55-70 years), and 16 patients (42%) were female (Table 1). Fifty percent of patients were followed for >4.9 years, 25% for >12 years, 10% for >18 years, and 5% for >20 years. The date of last follow-up was March 2, 2023. The calculated total potential patient-years of follow-up in this series was 287, and the observed patient-years of follow-up was 253, yielding a completeness of follow-up patient-years of 88% (Figure E1). Data were obtained from an institutional quality database and medical record review. The Cleveland Clinic Institutional Review Board approved this study and use of these data for research (approval 22-038 on July 10, 2023), with a waiver of informed consent.

Endpoints

The primary endpoint was operative mortality, defined as in-hospital death from any cause or death within 30 days of the index operation for patients discharged alive before 30 days. We examined operative mortality overall and stratified patients based on the era of re-repair (before January 2001 vs after January 2001) and the presence of preoperative temporary mechanical circulatory support (tMCS). Secondary endpoints included the presence of residual or recurrent shunt after re-repair, as assessed by intraoperative post-cardiopulmonary bypass or postoperative echocardiography prior to discharge, respectively, and postoperative complications. The postoperative complications assessed were new permanent pacemaker placement, new atrial fibrillation, sepsis, deep sternal wound infection, stroke, renal failure, new-onset dialysis, and reoperation for bleeding. Postoperative time-related mortality was analyzed as well.

Statistical Analysis

All analyses were conducted using R statistical software. Categorical variables are summarized as frequency count with percentage; continuous variables, as median with 15th and 85th percentiles (equivalent to ±1 SD). Postoperative survival out to 10 years from the date of post-MI VSR re-repair was estimated nonparametrically using the Kaplan-Meier method with corresponding 68% confidence intervals. Survival analyses were conducted for patients overall, as well as stratified by era of repair (before January 2001 vs after January 2001), presence of preoperative tMCS, and residual versus recurrent post-MI VSR.

RESULTS

Preoperative Characteristics

Among the 38 patients who underwent post-MI VSR re-repair, 20 (53%) underwent initial repair at our institution and 18 (47%) did so at an outside hospital. Diagnosis was established intraoperatively immediately after initial repair in 13 patients (34%) (residual) and postoperatively in 25 patients (66%) (recurrent). All patients had previously undergone sternotomy during their initial post-MI VSR repair, with 6 patients (16%) having undergone 2 previous sternotomies. Presenting symptoms included dyspnea on exertion in 19 patients (53%), dyspnea at rest in 23 (64%), and angina in 6 (17%). Most patients presented with stable hemodynamics, but 5 (13%) presented in cardiogenic shock (Table 1).

Preoperatively, 14 patients (37%) were on tMCS, including 12 patients on an isolated intra-aortic balloon pump (IABP), 1 patient on isolated extracorporeal membrane oxygenation (ECMO), and 1 patient on an IABP and ECMO. Placement of tMCS devices occurred at our institution in 11 patients and at an outside hospital prior to transfer in 3 patients.

The median left ventricular ejection fraction was 40% (15th-85th percentile, 30%-47%) and left ventricular dysfunction was classified as moderate in 12 (36%) and severe in 5 (15%) patients. Nine patients (24%) had moderate mitral regurgitation and 5 (13%) had severe mitral regurgitation; 14 (37%) had moderate tricuspid regurgitation and 6 (16%) had severe tricuspid regurgitation. No patients had moderate or severe aortic regurgitation. Preoperative median creatinine was 1.3 mg/dL (15th-85th percentile, 0.9-2.2 mg/dL), median total bilirubin was 0.9 mg/dL (15th-85th percentile, 0.4-1.7 mg/dL), and median hemoglobin was 12 g/dL (15th-85th percentile, 9.8-14.1 g/dL). The most common location for the VSR was inferoposterior

TABLE 1. Patient characteristics (N = 38)

Characteristic	N with data available	Value
Female sex, n (%)	38	16 (42)
Age, y, median (15th-85th percentile)	38	64 (55-70)
Body mass index, kg/m^2, median (15th-85th percentile)	36	26 (22-30)
Race, n (%)	37	
Caucasian		36 (97)
Black		0 (0)
Other		1 (2.6)
Comorbidities, n (%)		
Congestive heart failure	38	28 (74)
Atrial fibrillation/flutter	38	9 (24)
History of ventricular tachycardia/fibrillation	38	3 (7.9)
Chronic obstructive pulmonary disease	38	5 (13)
Diabetes requiring treatment	38	11 (29)
Hypertension	38	24 (63)
Peripheral arterial disease	38	3 (7.9)
Smoking	38	23 (61)
Prior stroke/cerebrovascular accident	38	3 (7.9)
Cerebrovascular disease (prior stroke or carotid disease)	38	6 (16)
Prior cardiac surgeries, n (%)	38	
1		32 (84)
2		6 (16)
Conditions at presentation, n (%)		
New York Heart Association functional class	36	
I		4 (11)
II		12 (33)
III		10 (28)
IV		10 (28)
Dyspnea on exertion	36	19 (53)
Dyspnea at rest	36	23 (64)
Angina	36	6 (17)
Cardiogenic shock	36	5 (14)

(n = 23; 61%), attributed primarily to dominant right coronary artery infarction (n = 22; 58%) or dominant left circumflex artery infarction (n = 1; 2.6%). Six patients (16%) had a concomitant left ventricular aneurysm (Table 2).

Intraoperative Details

Re-repair was performed electively in 20 patients (53%), urgently in 12 (32%), and as an emergency in 6 (16%). In patients undergoing urgent surgery, 7 (58%) were supported preoperatively with IABP only and 1 (8%) was supported with both ECMO and IABP. Among the 6 patients who

TABLE 2. Ventricular septal rupture and intraoperative details (N = 38)

Operation details	Value
Surgery status, n (%)	
Elective	20 (53)
Urgent	12 (32)
Emergency	6 (16)
VSR location, n (%)	
Anterior	11 (29)
Apical	4 (11)
Inferoposterior	23 (61)
Culprit artery, n (%)	
Left anterior descending	15 (39)
Left circumflex (dominant)	1 (2.6)
Right coronary (dominant)	22 (58)
LV aneurysm/ pseudoaneurysm, n (%)	6 (16)
Anterior	2 (5.3)
Inferoposterior	4 (11)
Indication for re-repair, n (%)	
Residual VSR	13 (34)
Recurrent VSR	25 (66)
Cardiac incision type, n (%)	
Right ventriculotomy	2 (5.3)
Left ventriculotomy	24 (63)
Right atriotomy	12 (29)
VSR re-repair technique, n (%)	
Patch closure	25 (66)
Suture closure only	8 (22)
Infarctectomy and patch closure	3 (8.1)
Infarct exclusion	1 (2.6)
Amputation	1 (2.6)
Type of VSR patch material, n (%)	
Bovine pericardium	16 (42)
Dacron	6 (16)
Autologous pericardium	2 (5.3)
Teflon	1 (2.6)
Gore-Tex	2 (5.3)
Unspecified	1 (2.6)
Cardiac incision closure technique, n (%)	
Sutures only	30 (53)
Patch with bovine pericardium	7 (18)
Patch with Dacron	1 (2.6)
Total myocardial ischemia, min, median (15th-85th percentile)	102 (63-144)
Total cardiopulmonary bypass, min, median (15th-85th percentile)	167 (97-199)

VSR, Ventricular septal rupture; *LV*, left ventricular.

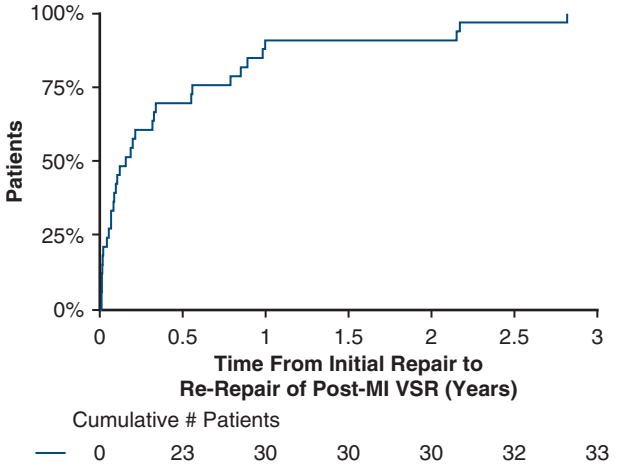

FIGURE 1. Time from initial repair to re-repair of post–myocardial infarction (*MI*) ventricular septal rupture (*VSR*). Most patients who required re-repair of a post-MI VSR presented early after initial repair, but others presented later.

underwent emergency surgery, all presented with cardiogenic shock and were supported preoperatively with IABP. Table E1 shows the trajectory of the tMCS used preoperatively in patients who underwent urgent and emergency surgery. The median time from initial post-MI VSR repair to re-repair was 55 days (15th-85th percentile, 5-331 days; n = 33) (Figure 1). The indication for re-repair was the presence of a hemodynamically significant residual VSR after initial open surgical repair in 13 patients (34%) and diagnosis of a hemodynamically significant recurrent VSR during postoperative follow-up in 25 patients (66%). One patient (2.6%) developed VSR recurrence following infection of their initial patch repair. One patient (2.6%) underwent re-repair after a failed attempt at percutaneous closure of their recurrent VSR. This was the only patient for whom a percutaneous closure was attempted for a residual or recurrent VSR, as our preferred technique is surgical re-repair.

The approach to re-repair varied, with a left ventriculotomy in 23 patients (61%), right atriotomy in 13 (34%), and right ventriculotomy in 2 (5%). Various surgical techniques were used for VSR re-repair, including patch closure only in 25 patients (66%), suture closure only in 8 (21%), infarctectomy and patch closure in 3 (7.9%), left ventricular apex amputation in 1 (2.6%), and infarct exclusion in 1 (2.6%). All patients with left ventricular aneurysms (n = 6; 16%) had concomitant aneurysm repairs. Closure of the cardiac incision was primarily achieved using sutures only (n = 30; 53%), with some patients undergoing closure with a bovine pericardium patch (n = 7; 18%) or polyester patch (n = 1; 2.6%). Concomitant cardiac procedures were performed in 29 patients (76%), with tricuspid valve repair (n = 12; 32%), mitral valve repair (n = 9; 24%), and coronary artery bypass grafting (n = 7; 18%) being the most common (Table 3). The median myocardial ischemia time

TABLE 3. Concomitant cardiac surgery (N = 38)

Procedure	n (%)
Concomitant cardiac surgery (any)	29 (76)
Coronary artery bypass grafting	7 (18)
Aortic valve replacement	1 (2.6)
Mitral valve repair	9 (24)
Mitral valve replacement	2 (5.3)
Tricuspid valve repair	12 (32)
Tricuspid valve replacement	2 (5.3)
Ablation for atrial fibrillation	1 (2.6)
ASD/PFO closure	2 (5.3)

ASD, Atrial septal defect; *PFO*, patent foramen ovale.

was 102 minutes (15th-85th percentile, 63-144 minutes), and the median cardiopulmonary bypass time was 167 minutes (15th-85th percentile, 97- 199 minutes). On postbypass intraoperative echocardiography, 1 patient (2.6%) had a small (<1 cm in diameter) residual VSR without hemodynamically significant shunting, and no further intervention was performed.

Postoperative Mechanical Circulatory Support

Following surgical re-repair, 20 patients (53%) left the operating room on isolated IABP support. Among these, 10 patients had a preoperative isolated IABP in place that was maintained postoperatively, and 10 patients had a new isolated IABP inserted intraoperatively for weaning from cardiopulmonary bypass. Two patients who had preoperative isolated IABPs died intraoperatively. The patient on isolated preoperative ECMO was decannulated during the same operation as the re-repair. The patient on preoperative ECMO and IABP support was maintained on both postoperatively, eventually necessitating implantation of a right ventricular assist device to facilitate ECMO decannulation and IABP removal.

Postoperative Outcomes

The median intensive care unit stay was 74 hours (15th-85th percentile, 13-235 hours), the median postoperative stay was 11 days (15th-85th percentile, 7-24 days), and the median total hospital stay was 18 days (15th-85th percentile, 9-39 days) (Table 4). Postoperative complications included renal failure in 8 patients (21%), new-onset dialysis in 6 (16%), stroke in 6 (16%), deep sternal wound infection in 3 (7.9%), and reoperation for bleeding in 3 (7.9%). A small (<1 cm diameter) recurrent VSR was identified in 1 patient (2.6%) on postoperative day 2, but no additional interventions were performed due to a lack of hemodynamic significance. Operative mortality occurred in 12 patients (32%), with a notable difference

TABLE 4. Postoperative outcomes (N = 38)

Outcome	Value
ICU length of stay, h, median (15th-85th percentile)	74 (13-235)
Operative length of stay, d, median (15th-85th percentile)	11 (7-24)
Hospital length of stay, d, median (15th-85th percentile)	18 (9-39)
On isolated IABP leaving OR, n (%)	20 (53)
Permanent pacemaker placement, n (%)	1 (2.6)
Atrial fibrillation, n (%)	6 (16)
Sepsis, n (%)	7 (18)
Deep sternal wound infection, n (%)	3 (7.9)
Stroke, n (%)	6 (16)
Renal failure, n (%)	8 (21)
New-onset dialysis, n (%)	6 (16)
Reoperation for bleeding, n (%)	3 (8)
Operative mortality, n (%)	12 (32)

ICU, Intensive care unit; *IABP*, intra-aortic balloon pump; *OR*, operating room.

between patients who underwent re-repair prior to January 2001 (n = 10/18; 56%) and those who underwent re-repair thereafter (n = 2/20; 10%) (Figure 2). Operative mortality also was higher in patients who were on preoperative tMCS (n = 8/14; 57%) compared to those who were not (n = 4/24; 17%).

Overall postoperative survival was 63% at 1 years, 57% at 5 years, and 50% at 10 years (Figure 3). Survival at 1, 5 and 10 years was 39%, 33% and 33% respectively, in patients undergoing re-repair before January 2001 and 85%, 79%, and 64%, respectively, in those undergoing re-repair in/after 2001. Survival at 1, 5, and 10 years was 83%, 78%, and 68%, respectively, in patients who did not receive preoperative tMCS, compared to 29%, 19%, and 19% in those who did receive preoperative tMCS. Survival at 1, 5, and 10 years was 54%, 54%, and 43%, respectively, in patients undergoing re-repair of a residual VSR and 67%, 58%, and 54%, respectively, in those undergoing re-repair of a recurrent VSR. Tables E2-E5 present all the variables studied, stratified by residual VSR versus recurrent VSR.

DISCUSSION

Principal Findings

This single-center study examined 38 consecutive patients who underwent re-repair of a post-MI VSR, revealing a spectrum of presentations varying from minimal heart failure symptoms to overt cardiogenic shock necessitating tMCS as a bridge to reoperation. Postoperative complications were frequently encountered following these high-risk procedures, with an overall operative mortality of 32%. Further stratification demonstrated higher mortality in patients requiring preoperative tMCS and lower mortality in patients undergoing re-repair in the more recent era.

Prevalence and Spectrum of Presentation

Published reports of VSR recurrence after initial open surgical repair demonstrate considerable variability, ranging from 10% to 44%.[9-16] More recently, an international multicenter study involving 475 patients highlighted a postoperative presence of residual or recurrent VSR of 13%, with 42% of these undergoing reoperation.[4] A systematic review and meta-analysis reported a VSR recurrence rate of 21% after initial repair, with 7.4% of all patients undergoing reintervention.[5] These findings, along with our present results, underscore the not uncommon occurrence of residual or recurrent post-MI VSR following the initial repair and the importance of meticulous postoperative surveillance.

Furthermore, the varying degrees of presentation acuity observed among patients undergoing post-MI VSR re-repair in our cohort also emphasize the importance of routine and thorough surveillance following the initial repair. This approach may facilitate earlier detection of patients with a recurrent or residual post-MI VSR and improve longitudinal monitoring of the hemodynamic significance and progression of these lesions, which may support more timely identification of patients who may benefit from earlier re-repair before clinical deterioration. In our case series, patients requiring preoperative support with tMCS had higher operative and long-term mortality compared to those who did not require tMCS. These findings also suggest that acute states and hemodynamic instability negatively impact postoperative outcomes, not only in patients presenting for the first time with post-MI VSR, but also in those with shunt recurrence necessitating re-repair.

Early Postoperative Outcomes in a High-Risk Cohort

The occurrence of postoperative complications following re-repair of post-MI VSR may reflect the high perioperative risk inherent to these patients. Patients in our cohort experienced significant burdens of postoperative infection, renal failure, and stroke. Notably, however, reoperation for bleeding in our series was similar to the 7.8% to 11% reported in previous studies of patients undergoing initial post-MI VSR repair.[2,4] The risk of postoperative complications is further amplified in unstable patients undergoing emergency operations, again emphasizing the importance of enhanced surveillance following initial repair.[2,4,5,17] Given the potential for impactful complications in these

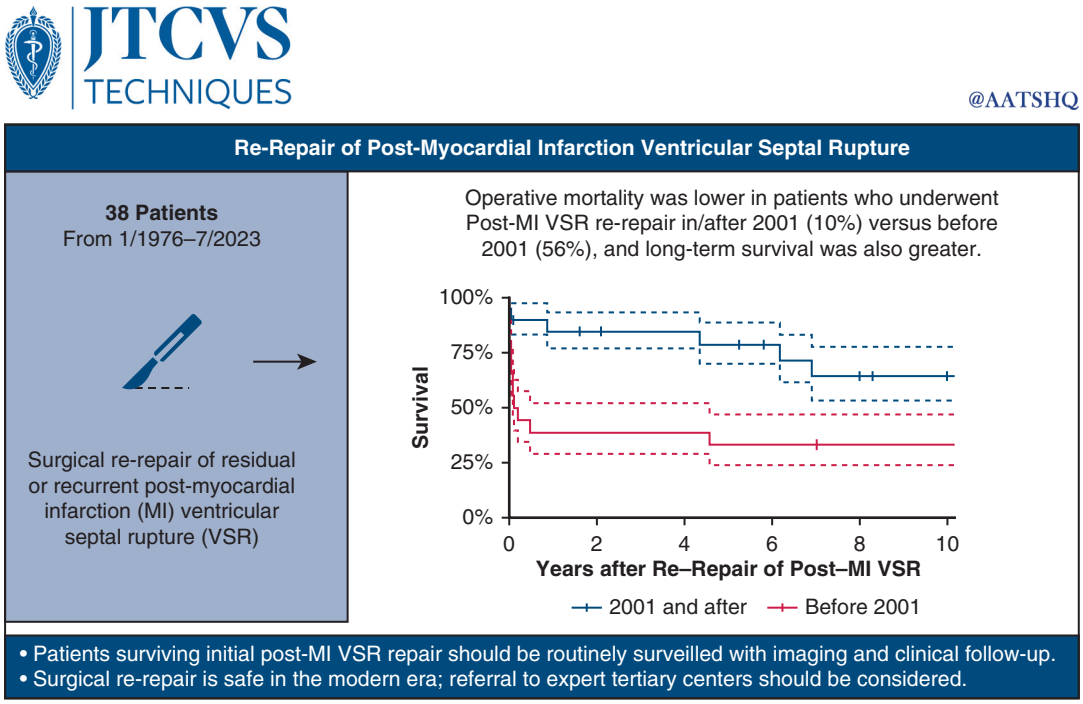

FIGURE 2. Graphical abstract. *MI*, Myocardial infarction; *VSR*, ventricular septal rupture.

patients, referral for surgery at expert tertiary centers is likely critical. It is well established that increasing procedural volume is associated with improved outcomes in cardiac surgery, as well as with more favorable failure to rescue following complications, both of which are likely of particular importance in this high-risk population.[18]

Furthermore, in our cohort, only 2 patients were diagnosed with residual or recurrent VSR prior to discharge following re-repair, both of which were small (<1 cm diameter) and hemodynamically insignificant. Although long-term echocardiographic follow-up was not available in this study, our findings suggest that re-repairs have favorable short-term durability. In our anecdotal experience, key factors that contribute to surgical success for re-repairs are similar to those for first time post-MI VSR repair operations[2,4,17] and include improved preoperative hemodynamic and end-organ stability, and elective/urgent intervention as opposed to emergency surgery. Additionally, a longer time between the initial MI and surgical intervention typically allows for increased fibrosis of the septum, which may improve the durability of repairs. However, these hypotheses require further investigation to provide higher-level evidence.

Postoperative Survival in the Modern Era

In our series, operative mortality also was lower in patients who underwent post-MI VSR re-repair in 2001 or later. Improvements in operative techniques, including myocardial protection, and perioperative management along with increasing center experience might have played a role in the improved outcomes over time.[18] Notably, only 1 patient in our series had percutaneous closure attempted, which ultimately failed and necessitated open surgical re-repair. Although favorable results with percutaneous closure of recurrent VSR have been reported, in our experience, we have had limited success with percutaneous techniques and thus typically prefer open surgical repair, which may provide a more complete and durable solution.[19] Additionally, given the high perioperative risk associated with post-MI VSR re-repairs, many patients may be turned down for reoperative surgery. However, the results from our experience suggest that re-repair in the current era can be performed at high-volume tertiary centers with relatively favorable operative mortality and long-term survival. Importantly, longitudinal follow-up demonstrated 50% survival at 10 years, with most deaths in our series occurring in the early postoperative period. This suggests that patients who survive the initial increased hazard phase may have reasonable potential for long-term survival. Also of note, no patient in our series underwent advanced therapy (durable left ventricular assist device or heart transplant) during follow-up.

Limitations

This study has several limitations stemming from its retrospective, single-center design, which might have

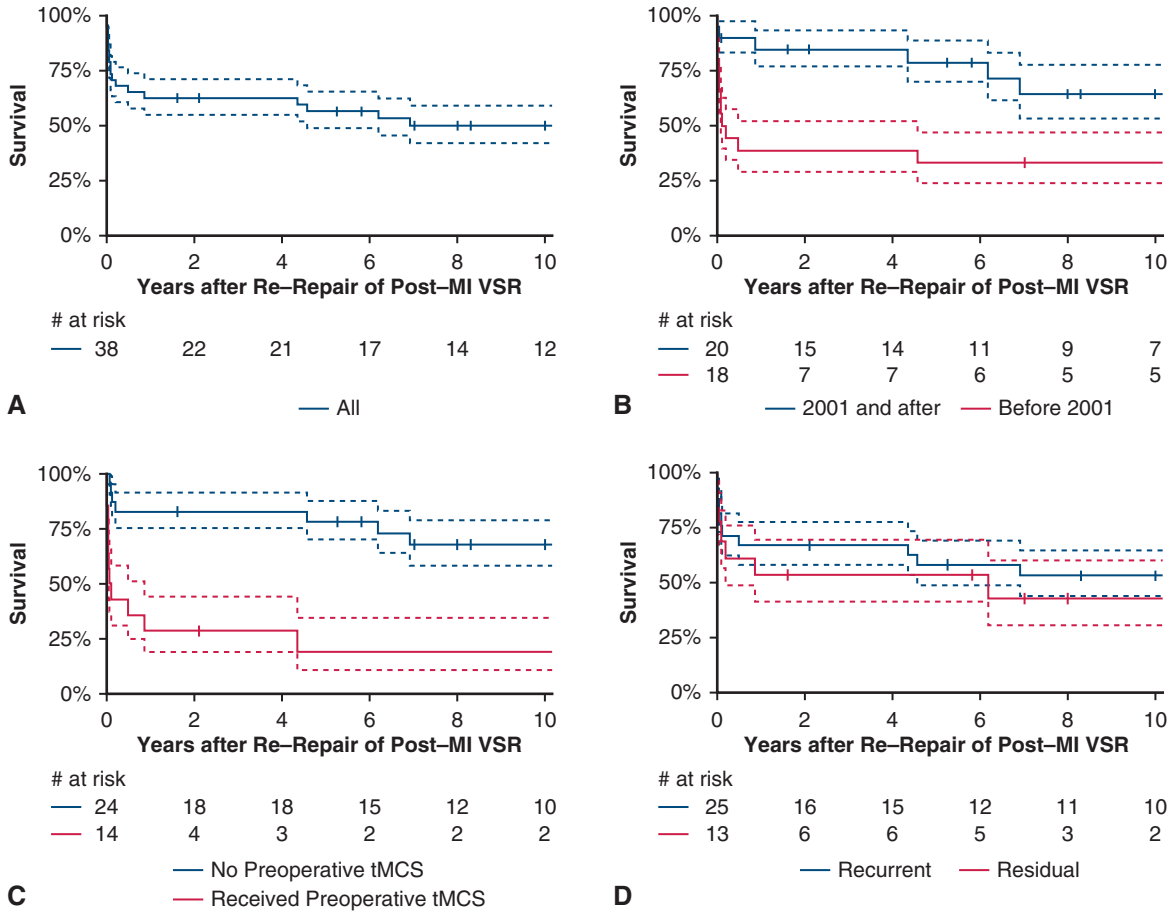

FIGURE 3. Postoperative survival after post-myocardial infarction (*MI*) ventricular septal rupture (*VSR*) re-repair. A, Survival overall. B, Survival stratified by era (before 2001 vs 2001 and after). B, Survival stratified by the presence of preoperative temporary mechanical circulatory support (*tMCS*). C, Survival stratified by residual versus recurrent post-MI VSR. D, Survival estimated by the Kaplan-Meier method from the date of post-MI VSR re-repair surgery (solid line). Vertical markers represent censored patients. The *dashed lines* represents 68% confidence interval. Numbers at risk are shown in the table.

introduced selection bias owing to institution-specific patient selection and management practices. We focused only on patients requiring re-repair and thus were unable to evaluate those with residual or recurrent post-MI VSR who did not undergo re-repair. Additionally, we assessed only surgical repairs, but the role of transcatheter and hybrid treatment options in these patients should be investigated in the future. Additionally, our study used only descriptive analyses without direct comparisons owing to the small series of patients affected by this relatively rare event. Furthermore, the historical nature of this cohort limited the availability of hemodynamic data. Although we assessed long-term postoperative survival, echocardiographic follow-up was not available after initial discharge. Moreover, we acknowledge the absence of evaluation of other clinical and patient-reported outcomes, such as quality of life and functional status, which are pivotal for assessing therapeutic efficacy beyond survival.

CONCLUSIONS

The patients who underwent re-repair for residual or recurrent post-MI VSR varied in their acuity of presentation, highlighting the importance of routine postoperative clinical and imaging surveillance following the initial repair. The greater operative mortality observed among patients requiring tMCS suggests that earlier recognition and intervention before clinical deterioration may improve outcomes. Although complications may be frequent, re-repair operations can be carried out with favorable results in the modern era at experienced centers. Patients who survive the early postoperative hazard phase have favorable potential for long-term survival.

Conflict of Interest Statement

Dr Soltesz reports honoraria from Abbott, Abiomed, AtriCure, and Dilon. Dr Tong reports honoraria from Abbott and Abiomed. Dr Roselli serves as a speaker, consultant,

and advisory board member for Artivion, Cook Medical, Edwards Lifesciences, W.L. Gore & Associates, Medtronic, and Terumo Aortic. Dr Gillinov serves as a consultant for Edwards, Medtronic, Abbott, Artivion, AtriCure, ClearFlow, and Johnson & Johnson. All other authors reported no conflicts of interest.

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

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Key Words: reoperation, temporary mechanical circulatory support, postoperative complications, survival

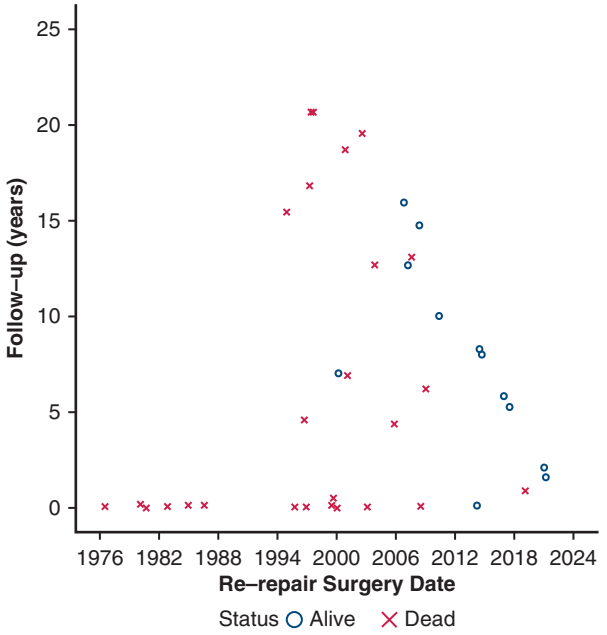

FIGURE E1. Goodness of follow-up plot. Fifty percent of patients were followed for >4.9 years, 25% for >12 years, 10% for >18 years, and 5% for >0 years. The date of last follow-up was March 2, 2023. The calculated total potential patient years of follow-up in this series is 287, and the observed patient-years of follow-up is 253, yielding 88% completeness of follow-up patient-years.

TABLE E1. Trajectory of tMCS in urgent and emergency re-repairs (N = 18)

Surgical status	Trajectory of tMCS
Urgent	No tMCS used
Urgent	ECMO placed preadmission and removed intraoperatively, IABP placed intraoperatively and removed postoperatively
Urgent	IABP placed preadmission and removed postoperatively
Urgent	No tMCS used
Urgent	No tMCS used
Urgent	IABP placed intraoperatively and removed postoperatively
Urgent	IABP placed intraoperatively and removed postoperatively
Urgent	IABP placed preadmission and removed postoperatively
Urgent	No tMCS used
Urgent	IABP placed preoperatively and removed postoperatively
Urgent	IABP placed preoperatively and removed postoperatively
Urgent	IABP placed preoperatively and removed postoperatively
Emergency	IABP placed preoperatively and removed postoperatively
Emergency	IABP placed preoperatively, and patient died intraoperatively with IABP in place
Emergency	IABP and ECMO placed preoperatively, and both removed postoperatively; RVAD placed postoperatively after removing IABP/ECMO, and patient died postoperatively with an RVAD in place
Emergency	IABP placed preoperatively, and patient died intraoperatively with IABP in place
Emergency	IABP placed intraoperatively and removed postoperatively
Emergency	IABP placed preoperatively and removed postoperatively

tMCS, Temporary mechanical circulatory support; *ECMO*, extracorporeal membrane oxygenation; *IABP*, intra-aortic balloon pump; *RVAD*, right ventricular assist device.

TABLE E2. Patient characteristics stratified by residual or recurrent etiology

Characteristic	N with data available	Residual (N = 13)	Recurrent (N = 25)	Total cohort (N = 38)
Female sex, n (%)	38	5 (38)	11 (44)	16 (42)
Age, y, median (15th-85th percentile)	38	63 (55-74)	66 (56-69)	64 (55-70)
Body mass index, kg/m^2, median (15th-85th percentile)	36	26 (25-30)	25 (22-30)	26 (22-30)
Race, n (%)	37			
Caucasian		12 (100)	24 (96)	36 (97)
Black		0 (0)	0 (0)	0 (0)
Other		0 (0)	1 (4.0)	1 (2.6)
Comorbidities, n (%)				
Congestive heart failure	38	10 (77)	18 (72)	28 (74)
Atrial fibrillation/flutter	38	6 (46)	3 (12)	9 (24)
History of ventricular tachycardia/fibrillation	38	3 (23)	0 (0)	3 (7.9)
Chronic obstructive pulmonary disease	38	3 (23)	2 (8)	5 (13)
Diabetes requiring treatment	38	5 (39)	6 (24)	11 (29)
Hypertension	38	8 (62)	16 (64)	24 (63)
Peripheral arterial disease	38	2 (15)	1 (4)	3 (7.9)
Smoking	38	8 (62)	15 (60)	23 (61)
Prior stroke/cerebral vascular accident	38	0 (0)	3 (12)	3 (7.9)
Cerebrovascular disease (prior stroke or carotid disease)	38	1 (7.7)	5 (20)	6 (16)
Prior cardiac surgeries, n (%)	38			
1		10 (77)	22 (88)	32 (84)
2		3 (23)	3 (12)	6 (16)
Conditions at presentation, n (%)				
New York Heart Association functional class	36			
I		2 (17)	2 (8.3)	4 (11)
II		3 (25)	9 (38)	12 (33)
III		3 (25)	7 (29)	10 (28)
IV		4 (33)	6 (25)	10 (28)
Dyspnea on exertion	36	8 (67)	11 (46)	19 (53)
Dyspnea at rest	36	6 (50)	17 (71)	23 (64)
Angina	36	3 (25)	3 (13)	6 (17)
Cardiogenic shock	36	2 (17)	4 (17)	5 (14)

TABLE E3. Ventricular septal rupture and intraoperative details stratified by residual or recurrent etiology

Operation details	Residual (N = 13)	Recurrent (N = 25)	Total cohort (N = 38)
Surgery status, n (%)			
Elective	7 (54)	13 (52)	20 (53)
Urgent	3 (23)	9 (36)	12 (32)
Emergency	3 (23)	3 (12)	6 (16)
VSR location, n (%)			
Anterior	4 (31)	7 (28)	11 (29)
Apical	1 (7.7)	3 (12)	4 (11)
Inferoposterior	8 (62)	15 (60)	23 (61)
Culprit artery, n (%)			
Left anterior descending	5 (38)	10 (40)	15 (39)
Left circumflex (dominant)	1 (7.7)	0 (0)	1 (2.6)
Right coronary (dominant)	7 (54)	15 (60)	22 (58)
LV aneurysm/pseudoaneurysm, n (%)	3 (23)	3 (12)	6 (16)
Anterior	1 (7.7)	1 (4.0)	2 (5.3)
Inferoposterior	2 (15)	2 (8.0)	4 (11)
Indication for re-repair, n (%)			
Residual VSR	13 (100)	0 (0)	13 (34)
Recurrent VSR	0 (0)	25 (100)	25 (66)
Cardiac incision type, n (%)			
Right ventriculotomy	0 (0)	2 (8.0)	2 (5.3)
Left ventriculotomy	7 (54)	17 (68)	24 (63)
Right atriotomy	5 (38)	7 (32)	12 (29)
VSR re-repair technique, n (%)			
Patch closure	7 (54)	18 (72)	25 (66)
Suture closure only	4 (31)	4 (16)	8 (22)
Infarctectomy and patch closure	0 (0)	3 (12)	3 (8.1)
Infarct exclusion	1 (7.7)	0 (0)	1 (2.6)
Amputation	1 (7.7)	0 (0)	1 (2.6)
Type of VSR patch material, n (%)			
Bovine pericardium	3 (15)	14 (48)	16 (42)
Dacron	1 (7.7)	5 (20)	6 (16)
Autologous pericardium	0 (0)	2 (8.0)	2 (5.3)
Teflon	0 (0)	1 (4.0)	1 (2.6)
Gore-Tex	1 (7.7)	1 (4.0)	2 (5.3)
Unspecified	1 (7.7)	0 (0)	1 (2.6)
Cardiac incision closure technique, n (%)			
Sutures only	11 (85)	19 (76)	30 (53)
Patch with bovine pericardium	2 (15)	5 (20)	7 (18)
Patch with Dacron	0 (0)	1 (4)	1 (2.6)
Total myocardial ischemia, min, median (15th-85th percentile)	84 (61-148)	104 (74-143)	102 (63-144)
Total cardiopulmonary bypass, min, median (15th-85th percentile)	172 (98-209)	165 (100-193)	167 (97-199)

VSR, Ventricular septal rupture; *LV*, left ventricular.

TABLE E4. Concomitant cardiac surgery details stratified by residual or recurrent etiology

Procedure	Residual (N = 13)	Recurrent (N = 25)	Total cohort (N = 38)
Concomitant cardiac surgery (any), n (%)	14 (100)	15 (60)	29 (76)
Coronary artery bypass grafting, n (%)	5 (38)	2 (8)	7 (18)
Aortic valve replacement, n (%)	1 (7.7)	0 (0)	1 (2.6)
Mitral valve repair, n (%)	6 (46)	3 (12)	9 (24)
Mitral valve replacement, n (%)	1 (7.7)	1 (4)	2 (5.3)
Tricuspid valve repair, n (%)	5 (38)	7 (28)	12 (32)
Tricuspid valve replacement, n (%)	1 (7.7)	1 (4)	2 (5.3)
Ablation for atrial fibrillation, n (%)	1 (7.7)	0 (0)	1 (2.6)
ASD/PFO closure, n (%)	0 (0)	2 (8)	2 (5.3)

ASD, Atrial septal defect; *PFO*, patent foramen ovale.

TABLE E5. Postoperative outcomes stratified by residual or recurrent etiology

Outcome	Residual (N = 13)	Recurrent (N = 25)	Total cohort (N = 38)
ICU length of stay, h, median (15th-85th percentile)	72 (33-220)	75 (14-267)	74 (13-235)
Operative length of stay, d, median (15th-85th percentile)	9 (8-22)	11 (7-24)	11 (7-24)
Hospital length of stay, d, median (15th-85th percentile)	15 (8-37)	20 (9-43)	18 (9-39)
On isolated IABP leaving OR, n (%)	5 (38)	15 (60)	20 (53)
Permanent pacemaker placement, n (%)	1 (8.3)	0 (0)	1 (2.6)
Atrial fibrillation, n (%)	2 (15)	4 (18)	6 (16)
Sepsis, n (%)	3 (23)	4 (16)	7 (18)
Deep sternal wound infection, n (%)	1 (7.7)	2 (8.0)	3 (7.9)
Stroke, n (%)	3 (23)	3 (12)	6 (16)
Renal failure, n (%)	3 (23)	5 (20)	8 (21)
New-onset dialysis, n (%)	1 (7.7)	5 (20)	6 (16)
Reoperation for bleeding, n (%)	2 (15)	1 (4.0)	3 (8)
Operative mortality, n (%)	5 (38)	7 (28)	12 (32)

ICU, Intensive care unit; *IABP*, intra-aortic balloon pump; *OR*, operating room.