Noncomplex ventricular arrhythmia associated with greater freedom from recurrent ectopy at 1 year after mitral repair surgery

Dimosthenis Pandis, MD, MSc,[a] Navindra David, BS,[b] Ahmed EI-Eshmawi, MD,[a] Marc A. Miller, MD,[c] Percy Boateng, MD,[a] Ana Claudia Costa, MD, PhD,[a] Philip Robson, PhD,[d] Maria Giovanna Trivieri, MD,[d] Zahi Fayad, PhD,[d] Anelechi C. Anyanwu, MD, MSc,[a] and David H. Adams, MD[a]

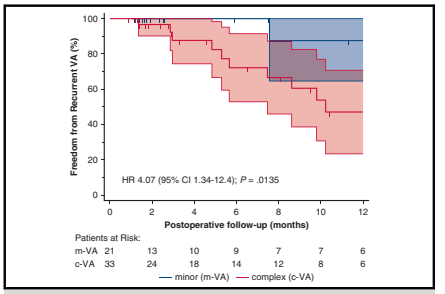
ABSTRACT

Objective: The effect of mitral valve (MV) surgery on the natural history of ventricular arrhythmia (VA) in patients with arrhythmic MV prolapse remains unknown. We sought to evaluate the cumulative incidence of VA at 1 year after surgical mitral repair.

Methods: A retrospective review of progressively captured data identified 204 consecutive patients who underwent elective MV repair for significant degenerative mitral regurgitation as a first-time cardiovascular intervention in a quaternary reference center between January 2018 and December 2020. A subset of 62 consecutive patients with diagnosed arrhythmic MV prolapse was further evaluated for recurrent VA after MV repair.

Results: The median age was 62 years (range, 27-77 years) and 26 of 62 (41.9%) were female. The median time from initial mitral regurgitation/MV prolaspe diagnosis-to-referral was 13.8 years (interquartile range [IQR], 5.4-25) and from VA diagnosis-to-referral was 8 years (IQR, 3-10.6). Using the Lown-Wolf classification, complex VA (Lown grade $\geq$3) was identified in 36 of 62 patients (58%) at baseline, whereas 8 of 62 (13%) had a cardioverter/defibrillator implanted for primary (4/8) or secondary (4/8) prevention. Left ventricular myocardial scar was confirmed in 23 of 34 (68%) of patients scanned at baseline. The prevailing valve phenotype was bileaflet Barlow (59/62; 95.2%). All patients underwent surgical MV repair by the same team. Surgical repair was stabilized with an annuloplasty prosthesis (median size 36 mm [IQR, 34-38]). Concomitant procedures included tricuspid valve repair (51/62; 82.3%), cryo-maze $\pm$ left atrial appendage exclusion (14/62, 23%), and endocardial cryoablation of VA ectopy (4/62; 6.5%). The 30-day and 1-year freedom from recurrent VA were 98.4% and 75.9%, respectively. Absent VA after mitral repair was uniformly observed in patients with minor VA at baseline. Absent VA after mitral repair was uniformly observed in patients with minor VA preoperatively. Complex baseline VA was the strongest predictor of recurrent VA (hazard ratio, 10.8; 95% confidence interval, 1.4-84.2; $P = .024$), irrespective of myocardial fibrosis.

Conclusions: In a series of 62 consecutive patients operated electively for arrhythmic mitral prolapse, VA remained undetected in 75.9% of patients at 1 year. Freedom from recurrent VA was greater among patients without complex VA preoperatively, whereas baseline Lown grade $\geq$3 was the strongest independent risk factor for recurrent VA at 1 year. These findings attest to the importance of early recognition and prompt referral of patients with mitral prolapse and progressive VA to specialty interdisciplinary care. (JTCVS Open 2024;19:94-113)



Greater freedom from recurrent VA after mitral repair with less severe VA at baseline.

CENTRAL MESSAGE

Arrhythmic mitral valve prolapse patients with noncomplex/sustained ventricular ectopy at baseline exhibit greater 1-year freedom from recurrent ventricular arrhythmia after mitral repair surgery.

PERSPECTIVE

The effect of mitral valve repair on ventricular arrhythmia (VA) in arrhythmic mitral valve prolapse patients remains unclear. Our study suggests that complex baseline VA (Lown grade $\geq$3) is an important independent risk factor for recurrent VA, with a more uniform postoperative effect in patients without complex/sustained VA. Careful follow-up of mitral prolapse patients with complex VA is warranted.

See Discussion on page 114.

From the [a]Department of Cardiovascular Surgery and [d]The BioMedical Engineering and Imaging Institute, [b]The Icahn School of Medicine at Mount Sinai; and [c]Helmsley Electrophysiology Center, Mount Sinai Hospital, New York, NY.

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Address for reprints: Dimosthenis Pandis, MD, Department of Cardiovascular Surgery, The Icahn School of Medicine at Mount Sinai, 1190 Fifth Ave, Box 1028, New York, NY 10029 (E-mail: Dimosthenis.pandis@mountsinai.org).

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Abbreviations and Acronyms

AMVP = arrhythmic mitral valve prolapse
CI = confidence interval
c-VA = complex ventricular arrhythmia
ECG = electrocardiogram
EHR = electronic health record
ICD = implantable cardiac defibrillator
IQR = interquartile range
LGE = late gadolinium enhancement
LV = left ventricle/-cular
MR = mitral regurgitation
MRI = magnetic resonance imaging
m-VA = minor ventricular arrhythmia
MVP = mitral valve prolapse
PET = positron emission tomography
PVC = premature ventricular contraction
SCA = sudden cardiac arrest
VA = ventricular arrhythmia
VT = ventricular tachycardia

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The evolving narrative for evaluating the quality of mitral repair has recently involved arrhythmic mitral valve prolapse (AMVP),[1] a term used to describe the subset of patients with degenerative mitral prolapse and concomitant ventricular arrhythmia (VA). Although frequent premature ventricular contractions (PVCs) can be observed in up to one-third of patients with mitral prolapse[2] irrespective of the degree of regurgitation, between 0.2% and 1.9% may develop sustained VAs and sudden cardiac arrest (SCA).[1] The small event rate in addition to incongruent operative outcomes from this patient subset[2] hinders the detection of potentially at-risk individuals and limits the generalizability of the reported outcomes to the greater patient demographic with degenerative mitral valve disease. As such, whether corrective mitral surgery may improve the burden of VA and lower the hazard from sudden cardiac death remains unknown,[2] mainly because of the contrasting results in relevant literature[3-7] confounded by patient selection, referral, and/or treatment allocation biases observed in the respective studies. Additional limitations arise from variations in VA origin, complexity, and underlying proarrhythmic substrate, which may prevent a uniform result after surgical correction of mitral valve prolapse (MVP).

As evidence from the Society of Thoracic Surgeons Adult Cardiac Surgery Database[8] suggests, the outstanding outcomes of mitral repair are a result of standardized operative strategies, selective referral of patients to centers of excellence, and careful patient management by a dedicated heart team.[9-11] We therefore sought to report our experience in patients undergoing mitral valve repair for chronic severe primary mitral regurgitation (MR) who have history of VA.

METHODS

Patient Selection

Electronic health records (EHRs) were queried for consecutive index surgical mitral repairs (isolated mitral repair ± tricuspid repair)[12] performed electively in our institution as first-time cardiovascular intervention for severe degenerative MR between January 1, 2018, and December 31, 2020. Identified mitral repairs were further ascertained for preoperative diagnosis of PVCs and whether they met criteria for AMVP diagnosis at the time of surgical referral. The study was approved by the Mount Sinai Institutional Review Board (STUDY-22-00800, August 29, 2022) and included a waiver of consent.

Definition of AMVP

The mechanism, disease etiology, and severity of degenerative mitral valve prolapse were confirmed on preoperative transthoracic echocardiography as previously defined.[13] VA was stratified as minor (m-VA) or complex (c-VA) according to the Lown-Wolf classification.[14] To summarize, c-VA = Lown grade ≥3 (ie, pleiomorphic PVCs, couplets/triplets, ventricular tachycardia [VT]) and m-VA = Lown grade 2 (ie, frequent, isolated unifocal PVCs). Patients with none or rare (<1/min or 30/h) isolated, monomorphic PVCs (Lown grade <2) were classified as non-VA and excluded. AMVP was defined as degenerative mitral prolapse with frequent or c-VA (grade ≥2).

Preoperative Screening

Eligible patients with guideline-recommended indications for mitral surgery[15] and documented history of PVCs were routinely referred for formal arrhythmia evaluation as part of our mitral repair reference center's practice standards for preoperative screening. Select patients with frequent/complex VAs undergo simultaneous 18-labeled fluorodeoxyglucose cardiac positron emission tomography (PET) and magnetic resonance imaging (MRI) with late gadolinium enhancement (LGE) on a hybrid PET/MRI system (Biograph mMR; Siemens Healthineers), as previously described.[16] This imaging modality allows for the detection and quantification of myocardial inflammation (PET+) and fibrosis (LGE+), which have been linked to the development of a proarrhythmic substrate for VA in myxomatous mitral prolapse, as recently reported by our group.[17,18]

Arrhythmia Evaluation and Risk Stratification

Baseline 12-lead electrocardiograms (ECGs; n = 62/62) and ambulatory rhythm monitoring (n = 48/62) were analyzed for the presence, morphology, and ectopic PVC burden. Patients without a baseline rhythm monitoring or if a previous one was not recent (<6 months) underwent a 24-hour Holter monitor followed by mobile cardiac outpatient event monitoring (7-14 days) as previously described.[17] New Holter requirement was ascertained according to the severity of baseline VA (ie, multifocal PVCs, couplets, triplets, nonsustained VT). Patients with very high PVC burden (>15%) with a predominant PVC origin morphology on ECG and positive hybrid cardiac PET/MRI uptake signal underwent direct endocardial PVC cryoablation at the time of mitral repair, as previously described.[6]

Perioperative and Recovery Considerations

Mitral repair was performed according to Carpentier's principles[19] using a combination of reconstructive techniques. The repair was true sized to the anterior leaflet height and stabilized with a mitral annuloplasty

prosthesis. Care was taken to minimize endogenous catecholamine circulation and blunt sympathetic surge with very deep narcotic-based intravenous induction and avoidance of potentially arrhythmogenic agents (ie, succinylcholine, epi-/norepinephrine, milrinone) where possible. Rigorous blood preservation, avoidance of pulmonary artery catheterization, and transfusion of blood/products were employed as per standard practice for elective mitral repair.

Follow-Up and Arrhythmia Monitoring

Clinical data from postoperative follow-up visits including physical examination, imaging, 12-lead ECG, Holter monitoring, and/or remote ambulatory telemetry reports were recorded from the cohort patients' EHRs and analyzed for adverse events including recurrent VA. To capture events from patient follow-up visits recorded in other institutions, we leveraged the health information exchange platform Care Everywhere, provided by Epic (our institutional EHR provider). As of October 2017, more than 1700 hospitals and 34,000 clinics are live on Care Everywhere and connected to more than 70,000 provider sites using other EHRs and health information exchanges.[20]

Statistical Analysis

Continuous variables are presented as medians with minimum-maximum or interquartile range (IQR). Assessment of between-group event rates was performed using a 2-sample *t* test or Wilcoxon rank-sum test, as appropriate, for continuous outcomes. Between-group differences were assessed using the χ^2 or Fisher exact test for categorical values, as appropriate. Paired sampled *t* test was used to compare continuous variables with different follow-up intervals. The cumulative probability of postoperative recurrent VA was estimated with Kaplan-Meier analysis. Predictors of recurrent VA were identified using Cox proportional hazards regression analysis. Statistically significant risk factors with $P < .15$ in univariate analysis were entered in the final multivariable model for backward regression analysis. The results are presented as hazard ratios with corresponding 95% confidence intervals (CIs). All tests are 2-tailed, and a P value $< .05$ is considered statistically significant. Statistical analysis was performed using Statistics Package for Social Sciences Statistics for Windows (SPSS), version 25 (IBM Corp) and MedCalc, version 22.007 for Windows (MedCalc Software Ltd).

RESULTS

From a cohort of 204 consecutive, unselected surgical mitral repair cases operated for severe degenerative MR as a first-time cardiovascular procedure, 62 patients met criteria for AMVP and were included for analysis. The final cohort (N = 62) comprised 36 patients with c-VA (58%) and 26 patients with m-VA (42%) (Figure E1).

Patient Characteristics

Baseline demographics, comorbidities, imaging, arrhythmia, and ECG-derived data are summarized in Table 1. MVP or MR (whichever came first) was diagnosed between the third and fourth decade of life (40.3 ± 17.2 years; 95% CI for the mean: 35.9-44.6). Diagnosis of VA was established on average 9 years after initial diagnosis of MVP/MR prolapse (95% CI for Δ: 3.95-14.5; $P = .0008$). Patients with c-VA were relatively younger at the time of surgery (55 vs 63.5 years old; $P = .029$) and diagnosed with VA at a younger age (47 vs 57.4 years old; $P = .007$). Self-reported familial mitral prolapse clustering, atrial fibrillation, and preoperative antiarrhythmic therapy (27.4%, 21%, and 37.1%, respectively) showed a trend for greater frequency in patients with c-VA. Of note, 75% of survivors of SCA endorsed a positive family history of mitral prolapse. Cardiac chamber dimensions and function were similar between VA subsets, including left ventricular (LV) strain and mechanical dispersion. Bileaflet prolapse was more common in patients with c-VA compared with m-VA (75% vs 50%; $P = .04$). Stratified by gender, bileaflet distribution was skewed toward male subject (67.7%; $P = .005$) with a trend favoring the c-VA subset (41.7% vs 19.2%; $P = .064$).

Myocardial fibrosis was identified in 68.6% of scanned patients and similar between VA subgroups. Focal or focal-on-diffuse inflammation (PET+) was detected in 86.4% of scanned patients and was concordant with areas of myocardial fibrosis (LGE+) in 84.2% of patients. Preoperative ambulatory rhythm monitoring (Holter/implantable cardiac defibrillator [ICD] interrogation) was completed in 35 of 36 patients with c-VA (97.2%) and 13 of 26 (50%) m-VA. The median baseline VA burden was overall low (0.97%) but significantly greater in c-VA, which consisted of 83.3% (30/36) patients with a history of VT and greater prevalence of conduction delays, predominantly right bundle branch block pattern.

Operative Characteristics

Patients were referred for mitral repair within 13.8 years (IQR, 5.4-24.8) after initial MVP/MR diagnosis. Of note, referrals of women tended to be delayed compared with referrals of men (19.9 vs 10.7 years; $P = .07$) despite their relatively earlier MVP diagnosis (Figure E2). Surgical referral was triggered primarily by functional deterioration (45.2%) followed by onset of symptomatic palpitations and/or progression of MR severity (21% for both). The operative risk profile was balanced between VA subsets with 0.42% median predicted risk of mortality. The predominant MVP phenotype was bileaflet Barlow disease with at least one flail leaflet segment identified in more than half of the study cohort, notably similar between VA subsets, whereas fibroelastic deficiency and isolated anterior leaflet prolapse were noted in a minority of patients with c-VA. Tricuspid valve repair was the most frequent concomitant procedure (82.3%), followed by atrial fibrillation cryoablation ± left atrial appendage exclusion (22.6%), and endocardial cryoablation of VA in 4 patients (6.5%), respectively (Table 2).

Procedural Outcomes

Patients were discharged home within 6.5 days (IQR, 5-9). Residual MR was trace/none in 61 of 62 patients (98.4%) and mild in one, at predischarge echocardiography. No operative death, myocardial infarction, recurrent MR, cardiac reintervention, or new pacemaker implantation

TABLE 1. Patient characteristics

n (%)/median (IQR)	All patients (N = 62)	m-VA (n = 26)	c-VA (n = 36)	*P* value
Demographics and comorbidities				
Age, y	59.5 (51-65)	63.5 (56-67)	55 (49.5-62.5)	.029
Age at MR/MVP diagnosis, y	42.4 (27.5-53)	50.5 (31-58)	41.2 (23-51)	.098
Age at VA diagnosis, y	50.8 (38-58.4)	57.4 (47.5-63.7)	46.7 (37.8-54.9)	.007
Symptoms functional class				.145
NYHA I	29 (46.8)	15 (57.7)	14 (38.9)	
NYHA II	28 (45.2)	8 (30.8)	20 (55.6)	
NYHA III	5 (8.1)	3 (11.5)	2 (5.6)	
Female	26 (41.9)	10 (38.5)	16 (44.4)	.64
Familial MVP	17 (27.4)	5 (19.2)	12 (33.3)	.223
Hypertension	28 (45.2)	11 (42.3)	17 (47.2)	.704
Diabetes mellitus	2 (3.2)	1 (3.8)	1 (2.8)	.816
Chronic lung disease	3 (4.8)	2 (7.7)	1 (2.8)	.377
Smoking	15 (24.2)	7 (26.9)	8 (22.2)	.902
Obstructive sleep apnea	3 (4.8)	0 (0)	3 (8.3)	.134
Secondary PHT	22 (35.5)	10 (38.5)	12 (33.3)	.679
Atrial fibrillation/flutter	13 (21)	3 (11.5)	10 (27.8)	.124
BP systolic, mm Hg	130 (118-137)	130 (120-142)	127 (112.5-132.5)	.157
BP diastolic, mm Hg	73.9 (68-81)	78.5 (68-83)	74 (68-80)	.461
Pulse Pressure, mm Hg	53 (44-63)	58 (50-64)	50 (44-60)	.139
Antiarrhythmic therapy	23 (37.1)	7 (26.9)	16 (44.4)	.162
Diuretic therapy	7 (11.3)	3 (11.5)	4 (11.1)	.958
Serum K+, mEq/L	4.2 (4.1-4.4)	4.2 (4-4.4)	4.3 (4.1-4.5)	.271
BNP, pg/mL	59 (26.9-108.2)	57.6 (23.8-123)	59 (29.8-105)	.825
Multimodality imaging				
Resting echocardiography	62 (100)	26 (100)	36 (100)	–
LV EF, %	63 (59-65)	64 (60-68)	62 (57.8-65)	.167
LVEDDi, cm/m^2	2.92 (2.7-3.2)	2.87 (2.6-3.1)	2.95 (2.67-3.2)	.617
LVESDi, cm/m^2	1.87 (1.67-2)	1.85 (1.7-2.06)	1.87 (1.66-2.05)	.96
LV mass(i), g/m^2 (range)	117.5 (100-131.6)	118.6 (97.7-131.7)	116.9 (102.4-131.4)	.765
LV wall stress ($\times 10^3$), dyn/cm^2	69.7 (51.2-83.3)	74.6 (56.5-81.2)	67.6 (48.4-88.3)	.485
Peak GLS, %	−25.5 (−27 to −23.5)	−25.9 (−26.8 to −24.3)	−25 (−27.3 to −23.1)	.315
LV mechanical dispersion, ms	50 (33.7-80.2)	40.9 (30.7-81)	52.2 (36.9-78.7)	.253
LAVi, mL/m^2	61.7 (54.2-89.6)	67.6 (54.3-91.4)	60.4 (54-83)	.406
PASP, mm Hg	28 (24-40)	27.3 (25-43)	28 (23.4-40)	.196
MV E/A	1.5 (1.13-1.77)	1.43 (1.15-1.66)	1.47 (1.13-1.87)	.523
MV E/e'	9.9 (7.3-12.9)	10.1 (8.9-14.1)	8.8 (7.3-12.5)	.28
Diastolic filling time, ms	512 (423-602)	488.7 (400.3-572.5)	513.5 (433-624)	.330
Bileaflet prolapse	40 (64.5)	13 (50)	27 (75)	.04
Bileaflet prolapse—female patients	20 (32.3)	5 (19.2)	15 (41.7)	.064
Cardiac MRI	36 (58.1)	13 (50)	23 (63.9)	.278
LV scar/fibrosis (LGE+)	24 (68.6)	9 (69.2)	15 (68.2)	.739
Preoperative hybrid PET/MRI	22 (35.5)	10 (38.5)	12 (33.3)	.679
LV inflammation (FDG+)	19 (86.4)	7 (70)	12 (100)	.046
Coronary anatomy				.168
Normal coronaries	44 (71)	16 (61.5)	28 (77.8)	
Nonobstructive CAD	18 (29)	10 (38.5)	8 (22.2)	
Baseline ventricular arrhythmia profile, complexity, and ECG characteristics				
MR diagnosis to VA, y	9 (4.4-22); (n = 45)	8 (3-20); (n = 22)	13 (6-27); (n = 23)	.146
VA diagnosis to MR, y	2 (1.9-3.5); (n = 17)	2.5 (1.9-3); (n = 4)	2 (1.8-6); (n = 13)	.817
Ambulatory rhythm monitor	48 (77.4)	13 (50)	35 (97.2)	<.0001
VA burden, % (range)	0.97 (0.01-47)	0.2 (0.01-10)	1.53 (0.1-47)	.006
Bigeminy	24 (39.3)	2 (7.7)	22 (62.9)	–

(Continued)

TABLE 1. Continued

n (%)/median (IQR)	All patients (N = 62)	m-VA (n = 26)	c-VA (n = 36)	*P* value
Pleiomorphic PVCs	21 (33.9)		21 (58.3)	
Ventricular couplets	26 (41.9)		26 (72.2)	
Ventricular tachycardia	30 (48.4)		30 (83.3)	
VA-related syncope	10 (16.1)		10 (27.8)	–
Sudden cardiac arrest	4 (6.5)		4 (11.1)	–
ICD	8 (12.9)		8 (22.2)	–
Heart rate, beats/min	66.5 (59-79)	68.5 (63-80)	65 (58.5-74)	.288
Sinus bradycardia	16 (25.8)	5 (19.2)	11 (30.6)	.318
QTc, ms	434.5 (420-446)	434.5 (421-453)	434.5 (420-446)	.643
QTc (age-adj), ms	433.4 (431-435)	434.6 (432.4-435.6)	432.1 (430.5-434.3)	.029
Prolonged QTc	22 (35.5)	11 (42.3)	11 (30.6)	.343
Prolonged QTc, ms	451.5 (446-457)	454 (442.8-466.3)	448 (446.3-455.8)	.645
Prolonged QTc (age-adj), ms	434.1 (432.7-434.7)	434.7 (434.1-435.7)	433.6 (428.9-434.4)	.012
QRS, ms (range)	97 (88-104)	98 (90-102)	95 (86-104)	.943
Nonspecific ST-T	15 (24.2)	7 (26.9)	8 (22.2)	.672
Repolarization abnormalities	9 (14.5)	4 (15.4)	5 (13.9)	.870
Inverted/biphasic T-waves	31 (50)	13 (50)	18 (50)	–
Infarct pattern	23 (37.1)	8 (30.8)	15 (41.7)	.385
T-wave inversion—inferior	7 (30.4)	1 (12.5)	6 (40)	.182
T-wave inversion—anterior	16 (69.6)	7 (87.5)	9 (60)	
Conduction delay	21 (33.9)	5 (19.2)	16 (44.4)	.040
1° AV block	8 (12.9)	2 (7.7)	6 (16.7)	.302
Fascicular block	13 (21)	3 (11.5)	10 (27.8)	.124
LBBB	1 (7.7)	1 (33.3)	–	.067
RBBB	12 (92.3)	2 (66.7)	10 (100)	
LVH-ECG voltage criteria	17 (27.4)	6 (23.1)	11 (30.6)	.518

IQR, Interquartile range; *m-VA*, minor ventricular arrhythmia; *c-VA*, complex ventricular arrhythmia; *MR*, mitral regurgitation; *MVP*, mitral valve prolapse; *VA*, ventricular arrhythmia; *NYHA*, New York Heart Association; *PHT*, pulmonary hypertension; *BP*, blood pressure; *BNP*, brain natriuretic peptide; *LV*, left ventricle/-cular; *EF*, ejection fraction; *EDDi*, end-diastolic diameter index; *ESDi*, end-systolic diameter index; *GLS*, global longitudinal strain; *LAVi*, left atrial volume index; *PASP*, pulmonary arterial systolic pressure; *MV*, mitral valve; *MRI*, magnetic resonance imaging; *LGE*, late gadolinium enhancement; *PET*, positron emission tomography; *FDG*, fluorodeoxyglucose; *CAD*, coronary artery disease; *ECG*, electrocardiogram; *MR*, mitral regurgitation; *PVC*, premature ventricular contraction; *ICD*, implantable cardioverter/defibrillator; *AV*, atrioventricular; *LBBB*, left bundle branch block; *RBBB*, right bundle branch block; *LVH*, left ventricular hypertrophy.

were observed at 30-day and 1-year follow-up (Table 3). One patient was reported with asymptomatic mild-moderate MR at 6-month surveillance echocardiography, which remained stable without symptoms and LV ejection fraction of 70% at 1 year.

Cryoablation of Ventricular Ectopy Foci

Endocardial cryoablation of ventricular arrhythmia foci was performed in 4 patients with c-VA: 2 bilateral papillary muscle cryoablation, 1 posteromedial papillary muscle only, and 1 LV summit cryoablation at the base of the left coronary aortic leaflet and into the interventricular septum, respectively. At 1 year, PVC burden decreased significantly in the former 2 (1.9% from 42%, and 11.4% from 20%, respectively) and was fully abated in the latter 2 cases, on pairwise comparison of Holter and/or remote ambulatory rhythm telemetry data at baseline and follow-up.

Postoperative Antiarrhythmic Regime

Unless contraindicated (ie, bradycardia [4/62] or hypotension [3/62]; atrioventricular block [4/62]), patients were discharged on low-dose metoprolol (n = 51; 82.3%). A tapered dose of oral amiodarone was added (n = 15; 24.2%) for the management of supraventricular tachyarrhythmias (12/15; 80%) and nonsustained ventricular ectopy (3/15; 20%) during postoperative recovery (Table 2). After hospital discharge, titration of antiarrhythmic therapy was managed by the respective patient's referring cardiology service.

Follow-up Data Collection

One-year data including clinical events, echocardiography, and rhythm monitoring were available for 54 of 62 patients (87%); 8 patients were lost to follow-up. Medication prescription data were available for 50 of 54 (92.6%) of patients at 1 year.

VA Recurrence

The median follow-up was 11.2 months (IQR, 1.6-30.7). All patients were discharged in normal sinus rhythm and 61 of 62 (98.4%) remained in normal sinus rhythm without recurrent VA at 30 days based on continuous rhythm monitoring (including serial 12-lead ECG, Holter, and/or interrogation of remote ambulatory telemetry

TABLE 2. Surgical referral and operative characteristics

n (%)/median (IQR)	All patients (N = 62)	m-VA (n = 26)	c-VA (n = 36)	*P*
MR diagnosis to surgery, y (range)	13.8 (5.4-24.8)	10.8 (5.4-20.4)	16.4 (5.4-27.6)	.339
Surgical referral trigger				
Dyspnea/exercise tolerance	28 (45.2)	9 (34.6)	19 (52.8)	.301
MR severity progression	13 (21)	8 (30.8)	5 (13.9)	
Palpitations	13 (21)	5 (19.2)	8 (22.2)	
Worsening LV dimensions/EF	8 (12.9)	4 (15.4)	4 (11.1)	
Operative indication				
ACC/AHA class I	43 (69.4)	16 (61.5)	27 (75)	.260
ACC/AHA class IIa	19 (30.6)	10 (38.5)	9 (25)	
STS PROM, %	0.42 (0.28-0.72)	0.39 (0.24-0.74)	0.43 (0.3-0.68)	.804
DMR etiology				
Barlow—bileaflet	42 (67.7)	17 (65.4)	25 (69.4)	.674
Barlow—forme-fruste	16 (25.8)	7 (26.9)	9 (25)	
Fibroelastic deficiency	3 (4.8)	2 (7.7)	1 (2.8)	
Anterior leaflet prolapse	1 (1.6)		1 (2.8)	
Flail (chordal rupture/elongation)	36 (58.1)	17 (65.4)	19 (52.8)	.325
Segments repaired, n (range)	2 (1-6)	3 (1-6)	2 (1-5)	.526
Repair complexity score	3 (1-5)	3 (1-6)	2 (1-5)	.285
Simple	19 (30.6)	7 (26.9)	12 (33.3)	.824
Intermediate	26 (41.9)	11 (42.3)	15 (41.7)	
Complex	17 (27.4)	8 (30.8)	9 (25)	
Mitral ring size, mm	36 (31-34)	36 (32-38)	36 (34-38)	.514
Mitral annuloplasty prosthesis				
Flexible band	31 (50)	13 (50)	18 (50)	–
Remodeling ring	31 (50)	13 (50)	18 (50)	
Concomitant procedures				
Tricuspid valve repair	51 (82.3)	23 (88.5)	28 (77.8)	.281
LAA exclusion	16 (25.8)	4 (15.4)	12 (33.3)	.114
AF cryoablation	14 (22.6)	3 (11.5)	11 (30.6)	.079
Cox-maze IV	9 (64.3)	2 (22.2)	7 (77.8)	.926
Box PVI	5 (35.7)	1 (20)	4 (80)	
PFO closure	9 (14.5)	3 (11.5)	6 (16.7)	.575
AICD leads exchange	2 (3.2)	–	2 (5.6)	.226
CPB, min	118.5 (94-132)	109 (87-131)	120 (101-136.5)	.095
Crossclamp, min	88.5 (72-103)	83 (67.8-104)	95 (80.3-102.8)	.245
ICU stay, d	1.1 (0.93-2.08)	1.02 (0.9-1.9)	1.45 (0.93-2.9)	.166
Hospital stay, d	6.5 (5-9)	7 (5-9)	6 (5-8.5)	.629
Discharge antiarrhythmic				
Beta-blocker	36 (58.1)	17 (65.4)	19 (52.8)	.212
Beta-blocker + amiodarone	15 (24.2)	7 (26.9)	8 (22.2)	
Beta-blocker CI	11 (17.7)	2 (7.7)	9 (25)	

IQR, Interquartile range; *m-VA*, minor ventricular arrhythmia; *c-VA*, complex ventricular arrhythmia; *MR*, mitral regurgitation; *LV*, left ventricle/-cular; *EF*, ejection fraction; *ACC*, American College of Cardiology; *AHA*, American Heart Association; *STS PROM*, Society of Thoracic Surgeons Predicted Risk Of Mortality; *DMR*, degenerative mitral regurgitation *LAA*, left atrial appendage; *AF*, atrial fibrillation; *PVI*, pulmonary vein isolation. *PFO*, patent foramen ovale; *AICD*, automated implantable cardioverter defibrillator; *CPB*, cardiopulmonary bypass; *ICU*, intensive care unit; *CI*, contraindication.

recordings, accordingly). One patient developed recurrent, low-burden VA (2%) at postoperative day 27, after discontinuing their antiarrhythmic because of fatigue. Stratified by baseline VA profile, 30-day freedom from recurrent VA was 100% for m-VA and 97.2% for c-VA patient subsets ($P = .395$). At 1 year, antiarrhythmic therapy was maintained in 70% of patients with comparable rates between m-VA and c-VA subsets (77.8% vs 65.6%; $P = .408$).

The cumulative incidence of recurrent VA at 1 year was 24.1% (n = 13/54; Table 3) of whom 12 (92.3%; $P = .009$) were c-VA with preexisting VT. Remarkably, no

TABLE 3. Operative outcomes

n (%)	All patients (N = 62)	m-VA (n = 26)	c-VA (n = 36)	*P*
MAE (at 30 d)	5 (8.1%)	3 (11.5%)	2 (5.6%)	.397
Death	–	–	–	–
MI	–	–	–	–
Stroke	1 (1.6%)	1 (3.8%)	–	.239
Acute kidney injury	1 (1.6%)	–	1 (2.8%)	.395
Respiratory failure	3 (4.8%)	2 (7.7%)	1 (2.8%)	.377
Major bleeding	–	–	–	–
New PPM	–	–	–	–
Cardiac reintervention (any)	–	–	–	–
Residual MR >1+	–	–	–	–
Recurrent VA	1 (1.6%)	–	1 (2.8%)	.395
MAE (at 1 y)	All (N = 54)	m-VA (n = 21)	c-VA (n = 33)	
Recurrent MR >1+	–	–	–	–
Cardiac-related hospital admission	–	–	–	–
Cardiac reintervention (any)	–	–	–	–
Recurrent VA	13 (24.1%)	1 (4.8%)	12 (36.4%)	.009

m-VA, Minor ventricular arrhythmia; *c-VA*, complex ventricular arrhythmia; *MAE*, major adverse events; *MI*, myocardial infarction; *PPM*, permanent pacemaker; *MR*, mitral regurgitation; *VA*, ventricular arrhythmia.

further VT events were recorded postoperatively in 8 of those 12 patients (66.7%) on follow-up Holter and/or remote ambulatory telemetry. Four patients, including the survivor of SCA, had rare (1, 3, 2, and 1 event, respectively), asymptomatic nonsustained VT events on 1-year follow-up Holter (n = 3) and ICD telemetry (n = 1) and were maintained on antiarrhythmic therapy. Of note, 92.3% of patients with recurrent VA were on active antiarrhythmic therapy, considerably more compared with patients on antiarrhythmic medication but no VA recurrence at 1 year (62.2%; $P = .043$). The overall freedom from recurrent VA at 1 year was 75.9% and greater for m-VA compared with the c-VA subset (95.2% vs 63.6%; $P = .009$, Table 3). Patients with c-VA were 4 times more likely to experience postoperative VA recurrence (95% CI 1.3-12.4; $P = .014$, Figure 1). Furthermore, the median postoperative VA burden was reduced significantly in 7 of 13 (53.8%) patients with recurrent VA compared with baseline (1.9% from 20%; $P = .016$ for the median Δ: −18.9%) and remained stable at a low grade (0.9%) in the remaining 5 recurrent VA cases on pairwise comparison.

Predictors of Recurrent VA After Mitral Valve Repair

Table E1 summarizes the univariate prognostic value of all patient, imaging, ECG, and operative characteristics for VA recurrence after surgical mitral repair. Preexisting c-VA was the predominant independent predictor, increasing the hazard for postoperative VA recurrence by a factor of 10.8 (95% CI, 1.4-84.2; $P = .024$; C-index 0.80) (Table 4).

DISCUSSION

We assessed the 1-year outcomes of VA after elective, isolated mitral valve repair surgery in patients with VA and severe, chronic degenerative MR (Figure 2). The principal findings were (1) VA was absent in all patients in the immediate postoperative period (postoperative day 0 to discharge) and remained undetected at 30 days; (2) recurrent VA occurred in 24% of patients at 1-year follow-up, almost exclusively (92.3%) in those with previous VT and/or SCA; and (3) patients with complex VAs are more likely to experience recurrent VA after mitral repair.

The Natural History of AMVP Remains Unclear

Although all cohort subjects endorsed an innocuous onset of PVCs with sporadically perceived palpitations up to 3 years before being formally documented, some patients subsequently developed c-VA (Lown grade ≥3) whereas others did not. The reason for this divergence in the natural history of VA in patients with mitral prolapse is unclear. Furthermore, the inflection point from what one can assume to have been isolated unifocal PVCs to more sustained, complex VAs could not be identified. Patients with c-VA were generally diagnosed with mitral prolapse at a younger age compared with m-VA, and a syncopal or SCA episode was often the first documented event. Most female patients with c-VA in our cohort endorsed such events at a younger age and during conditions of adrenergic surge (ie, pre-labor; physical stress or emotional duress), whereas male patients with c-VA developed more sustained or severe VA relatively later in life and unrelated to physical/emotional stress. The etiology and timing of this unique electromechanical pattern variance remains unknown and warrants further study.

Recurrent Ventricular Arrhythmia Is Not Contingent on Mitral Surgery Itself

Although observational data show a uniform protective benefit of mitral repair from cardiovascular events across a

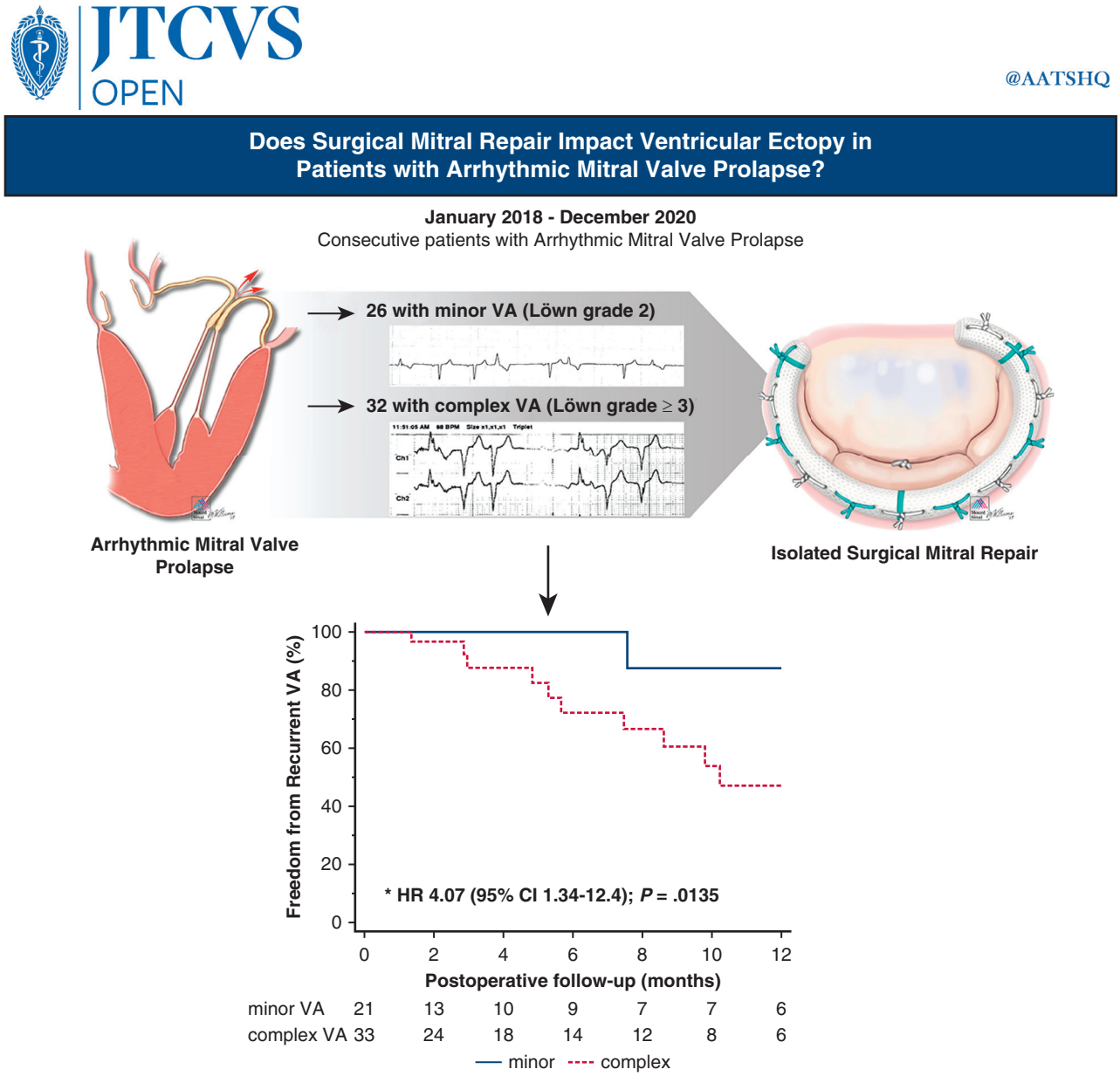

FIGURE 1. Arrhythmic mitral valve prolapse patients with non-complex/sustained ventricular ectopy at baseline exhibit higher 1-year freedom from recurrent VA after mitral repair surgery. Early diagnosis of patients with progressive PVC complexity (Lown grade >3) and referral to specialty multidisciplinary care is warranted. *VA*, Ventricular arrhythmia; *HR*, hazard ratio; *CI*, confidence interval; *PVC*, premature ventricular contraction.

wide range of surgeon volumes, expertise, and disease complexity,[21-23] outcome variability still persists.[24] This observation is attributed at least in part to patient and/or treatment variance although unaccounted factors have been implicated in confounding the observed outcomes.[25,26] The effect of mitral repair in minimizing recurrent VA is equally exposed to similar biases, which may explain the disparities in reported series.[3-5,27] Systematic differences in the identification mode of mitral prolapse or VA (patients selected from heart rhythm clinic registries vs from mitral prolapse surgical lists), differences in local referral patterns and treatment selection practices (patients allocated to intervention earlier are subject to different risk exposure to arrhythmia and MR from those operated later), have direct implications on the treatment effect of mitral repair in reducing the morbidity hazard from VA. Assuming a uniform effect from mitral repair mitigating the prolapse-related stretch/stress injury to the underlying myocardium, one should expect an equally uniform result in postoperative VA improvement with the proviso that the intervention is performed in comparable patient cohorts using comparable reconstructive techniques. All patients in our study had similar risk profiles and were operated on by the

TABLE 4. Risk factors associated with recurrent VA after mitral valve repair

Variable	Univariate log regression		Cox regression	
	OR (95% CI)	*P*	HR (95% CI)	*P*
Preoperative complex VA (Lown ≥3)	15.91 (1.9-131)	.01	10.8 (1.4-84.2)	.024
Arterial hypertension	4.85 (1.3-17.6)	.016	3.1 (0.8-11.4)	.089
QRS, ms	1.06 (1-1.13)	.04	1.04 (0.99-1.09)	.090
ECG infarct pattern	3.54 (1.1-11.8)	.04	–	–
Conduction delay	6.55 (1.84-23.3)	.004	–	–

OR, Odds ratio, *CI*, confidence interval; *VA*, ventricular arrhythmia; *HR*, hazard ratio; *ECG*, electrocardiogram.

same surgical team over 3 recent consecutive years using similar reconstructive principles. However, 1 in 5 patients developed recurrent VA within 1 year. It stands therefore to reason that additional factors beyond stretch/stress forces normalized by a successful mitral repair may be implicated in the etiopathogenesis and maintenance of ventricular electrical instability in the absence of additional acquired or congenital structural pathology and warrants further investigation.

Complex VA Begets Complex VA Regardless of Substrate or Surgery

Our data show that VA recurrence occurred almost exclusively in patients with preexisting c-VA (12/13; 92.3%), which was also the strongest predictor for postoperative VA, increasing the recurrence hazard by a factor of 10.8. Remarkably, most of the known markers related to the degree of LV adaptation to chronic volume loading and incremental MR severity or factors related to operative complexity and duration of ischemic arrest, were not associated with postoperative VA recurrence (Table E1). However, this patient subset had a greater incidence of hypertension (77% vs 37%, $P = 012$), conduction delays (left bundle branch block: 46% vs 17%, $P = .034$), and pleiomorphic PVCs (62% vs 24%, $P = .014$) at baseline (Table E2). Remarkably, we found that patients with minor VAs at baseline as well as those with complex PVCs (ie, couplets, triplets, pleiomorphic PVCs) but not sustained VAs (VT/SCA; n = 12/35) regardless of LGE status on preoperative MRI, did not experience recurrent VA after mitral repair. It appears that contrary to the outcome variability observed after mitral repair in patients with complex VAs, mitral repair had a more uniform favorable effect on patients with minor or nonsustained VAs, associated with absent ventricular ectopy up to 1 year postrepair. These

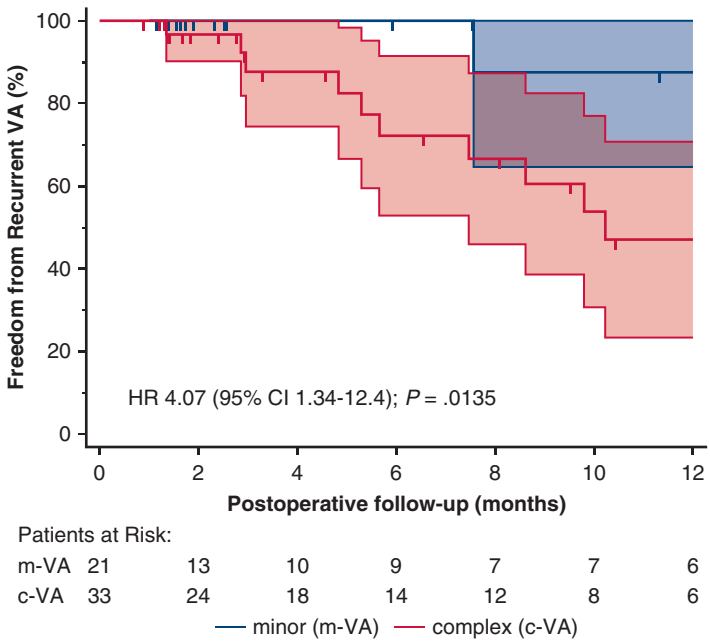

FIGURE 2. Freedom from recurrent VA. Kaplan-Meier curves with 95% CIs for postoperative VA-free probability stratified by baseline VA complexity. Presented % values represent the cumulative VA-free rates for each subset of preoperative VA over the postoperative follow-up period. Preoperative VA complexity has a significant influence on the time to recurrent VA (log-rank $P = .0135$), with preexisting complex VA associated with an incremental risk for postoperative recurrence compared with simple baseline VA (HR, 4.07; 95% CI, 1.34-12.4). *VA*, Ventricular arrhythmia; *HR*, hazard ratio; *CI*, confidence interval; *m-VA*, minor ventricular arrhythmia; *c-VA*, complex ventricular arrhythmia.

findings emphasize the importance of early diagnosis before the development of more complex/sustained VAs, when corrective mitral valve surgery may have a more predictable protective effect against recurrent ectopy.

Focal Myocardial Fibrosis Does Not Equate to Ventricular Arrhythmia Risk

One half of our patients with preoperative VT/SCA (n = 11/22) did not develop recurrent VA within 1 year despite a positive baseline LGE in 46.2% (6/11), which raises the question of prognostic value when LGE is used in isolation. Recent evidence from a large countywide postmortem analysis of more than 1000 consecutive adult sudden cardiac deaths[28] found that only 31% of MVP-related cases exhibited focal myocardial fibrosis and mitral annular disjunction, another marker linked to regional myocardial fibrosis,[29,30] and considered by some investigators to increase the risk of VA.[31,32] Kitkungvan and colleagues[33] corroborated similar prevalence of focal myocardial scar (LGE+) in 34.1% of 229 patients with MVP; however, the authors found that diffuse (instead of focal) interstitial fibrosis, inferred by extracellular volume, was independently associated with MR-related symptoms and clinical events. Similar observations were reported by Bui and colleagues,[34] where replacement fibrosis was only observed in a minority of patients with mitral prolapse (n = 11/41) with moderate or greater chronic primary MR, and LGE was not the major predictor of arrhythmic risk. These findings place the previously asserted hypothesis of focal myocardial scar as requisite substrate for arrhythmogenesis—and thus impervious to the benefit of reverse LV remodeling after corrective mitral surgery—in further uncertainty and shift the focus towards alternative mechanisms unrelated to traction forces[35] such as interstitial fibrosis. This may help generate impetus for larger-scale work to understand the mechanistic relationship between mitral prolapse and the adaptive myocardial ultrastructural alterations leading to electrical instability and manifest VAs.

Myocardial Inflammation—a Novel Marker of Arrhythmic Potential

Preoperative inflammation was present in 70% of scanned patients with m-VA and in 100% of patients with c-VA (Table 1). Importantly, PET+ inflammation was present in all asymptomatic patients with AMVP with preserved LV at baseline. Although PET/MRI readings were available from only 36% of the evaluated cohort, PET+ uptake suggests that this occult ultrastructural process may have a wider role in arrhythmogenesis and natural history of VA regardless of the degree of LV compensation and may be associated with a variety of PVC morphologies. Further evidence has recently emerged to describe the presence of myocardial inflammation during the early stages of degenerative mitral prolapse,[36] reinforcing our hypothesis and findings. As myocardial inflammation was present in both VA subsets with successful suppression of PVCs at 1 year (82.4%) and in 100% of cases with recurrent VAs (Table E2), this noninvasive method may provide important insight in the evolution and temporal expression of ectopic activity in patients with mitral prolapse and warrants further evaluation from larger case series.

AMVP Involves a Wide Spectrum of Valve Phenotypes

Although bileaflet Barlow was the predominant prolapse phenotype, the presence of a flail segment was not biased to patients with c-VA as previously suggested,[37] and it was equally present in patients without VA (grade <2). The presence of fibroelastic deficiency and forme-fruste anterior leaflet prolapse noted in a minority of patients with c-VA in our study further highlights the underappreciated diversity of the pathoanatomic spectrum encompassed by the so-called arrhythmic mitral prolapse syndrome, as the commonly postulated origins of ventricular arrhythmogenesis are incongruent when applied to differing degrees of MR severity, LV remodeling, and degenerative stigmata of mitral prolapse.[2]

Our cohort's risk profile and operative characteristics were similar between patients with/-out VA recurrence except for their baseline VA signature. In a series of 32 consecutive patients with AMVP and significant MR, although VA was not successfully suppressed after mitral surgery, Naksuk and colleagues[3] found that postoperative VA burden was decreased (>10%) in the younger subset (n = 53.1%; $P = .04$) of their cohort. Our findings are in contradistinction with this observation, as there was no age difference between VA recurrence subgroups or among patients with refractory VA with/-out postoperative ectopic burden reduction in our study (Table E2). Although not readily clear, a smaller sample size and a male prevalence in their nonreduction subset may have contributed in this disparity.

IMPLICATIONS FOR PRACTICE

Early Recognition: The Role of the Community Doctor

Identification of the AMVP patient phenotype should ideally begin at the primary care level. Early recognition of at-risk individuals should be followed with a thorough evaluation and surveillance protocol, establishment of appropriate risk modifiers (antiarrhythmic therapy, avoidance of adrenergic surge triggers, preventive ICD), and timely referral to specialty interdisciplinary team.

Does Concomitant VA Warrant Earlier Mitral Intervention?

Although MVP-related VA seems to follow a progressive course in its temporal distribution of severity (or complexity), we do not know when this inflection point actually happens in the course of mitral valve disease. In

addition, although some patients with MVP exhibit slow progression in VA burden and grade of severity (Lown ≤2), others may show evidence of c-VAs (Lown ≥3) including VT and SCA as early as the second decade of life when MR is not yet significant, LV dimensions are still small, and mitral surgery has no therapeutic role. However, patients with advanced myxomatous mitral prolapse (ie, Barlow disease) and at least moderate MR with complex VA (Lown grade ≥2) may benefit from the effect of mitral repair to alleviate prolapse-related traction forces on the papillary muscles and adjacent myocardium, thereby disrupting the stretch-activated pathway of arrhythmogenesis (Figure E3). When mitral prolapse and/or MR severity are less than significant and mitral intervention is not contemplated, complex VA should trigger a formal electrophysiologic evaluation and follow-up and prompt the physician to restratify such patients based on the incremental risk related to the expected progression of the arrhythmic substrate[38] and not solely on the advent of guideline-defined symptomatic and/or structural operative triggers.[39]

Limitations

Our analysis is vulnerable to bias inherent to the retrospective nature of our study and study sample selection from a quaternary mitral repair reference center. Furthermore, our patient sample does not include a comparator group with moderate or less MR, which introduces additional lead-time bias by excluding patients with AMVP without significant MR or survivors of SCA with existing MVP and less than moderate MR. The potential role of individual antiarrhythmic strategy during the follow-up period was not evaluated because of the limited sample size of the cohort's subgroups. However, the proportion of patients on antiarrhythmic regimes were comparable at discharge (Table 1) and greater among patients with recurrent VA at 1 year (Table E2), which could suggest a limited therapeutic advantage in influencing ectopic recurrence were it not confounded by sampling restrictions.

Determination of postoperative VA was based on Holter and/or ICD interrogation in all 13 patients with recurrent VA. For the remaining 41, recurrent VA was determined by Holter/ICD interrogation in 12 (30%) and by absent PVCs on serial ECGs plus a negative report of patient-perceived palpitations in the remaining 29 of 41 patients, which may have underestimated the incidence of recurrent VA. However, short ECG rhythm recording (up to 2-minute strip) is a validated alternative to longer ambulatory rhythm monitoring for ventricular ectopy.[40]

CONCLUSIONS

In a series of 62 consecutive patients operated electively for AMVP, VA remained undetected in 75.9% of patients at 1 year (Figure 1). Freedom from recurrent VA was greater among patients without c-VA preoperatively, whereas baseline Lown grade ≥3 was the strongest independent risk factor for recurrent VA at 1 year. These findings attest to the importance of early recognition and prompt referral of patients with mitral prolapse and progressive VA to specialty interdisciplinary care.

Webcast

You can watch a Webcast of this AATS meeting presentation by going to: https://www.aats.org/resources/surgical-mitral-valve-repair-improves-ventricular-ectopy-burden-in-arrhythmic-mvp-patients.

Conflict of Interest Statement

D.P. received nonfinancial support from TOMTEC Imaging Systems GmbH (PI - research license for myocardial strain analysis software). M.M. has served as a consultant to Boston Scientific. D.A. is the National co-Principal Investigator for the Triluminate-II US Pivotal Trials, the Medtronic Apollo and CoreValve US Pivotal Trials, and Re-Chord US Pivotal Trial, respectively. The Icahn School of Medicine at Mount Sinai receives royalty payments from Edwards Lifesciences and Medtronic for intellectual property related to D.A.'s involvement in the development of 3 mitral valve repair rings and a tricuspid valve repair ring. 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.

References

1. Miller MA, Dukkipati SR, Turagam M, Liao SL, Adams DH, Reddy VY. Arrhythmic mitral valve prolapse: JACC Review Topic of the Week. *J Am Coll Cardiol*. 2018;72(23):2904-2914. https://doi.org/10.1016/j.jacc.2018.09.048
2. Delling FN, Noseworthy PA, Adams DH, et al. Research opportunities in the treatment of mitral valve prolapse: JACC Expert Panel. *J Am Coll Cardiol*. 2022;80(24):2331-2347. https://doi.org/10.1016/J.JACC.2022.09.044
3. Naksuk N, Syed FF, Krittanawong C, et al. The effect of mitral valve surgery on ventricular arrhythmia in patients with bileaflet mitral valve prolapse. *Indian Pacing Electrophysiol J*. 2016;16(6):187. https://doi.org/10.1016/J.IPEJ.2016.10.009
4. Vaidya VR, DeSimone CV, Damle N, et al. Reduction in malignant ventricular arrhythmia and appropriate shocks following surgical correction of bileaflet mitral valve prolapse. *J Interv Card Electrophysiol*. 2016;46(2):137-143. https://doi.org/10.1007/s10840-015-0090-5
5. Hosseini S, Rezaei Y, Samiei N, et al. Effects of mitral valve repair on ventricular arrhythmia in patients with mitral valve prolapse syndrome: a report of two cases. *Int J Cardiol*. 2016;222:603-605. https://doi.org/10.1016/J.IJCARD.2016.08.053
6. El-Eshmawi A, Pandis D, Miller MA, et al. Surgical cryoablation of papillary muscle PVCs during mitral valve surgery: therapeutic consideration for malignant MVP. *J Am Coll Cardiol*. 2020;76(25):3061-3062. https://doi.org/10.1016/J.JACC.2020.10.037

7. Vohra J, Morton JB, Morgan J, Tatoulis J. Cryoablation of papillary muscles at surgery for malignant ventricular arrhythmias due to mitral valve prolapse. *Heart Lung Circ*. 2022;31(9):1285-1290. https://doi.org/10.1016/J.HLC.2022.04.058
8. Badhwar V, Chikwe J, Gillinov AM, et al. Risk of surgical mitral valve repair for primary mitral regurgitation. *Ann Thorac Surg*. 2023;115(3):600-610. https://doi.org/10.1016/J.ATHORACSUR.2022.12.024
9. Adams DH, Anyanwu AC. Revisiting the long-term goals of degenerative mitral valve repair: beyond eliminating mitral regurgitation. *J Am Coll Cardiol*. 2019;74(8):1054-1056. https://doi.org/10.1016/J.JACC.2019.07.023
10. Gillinov M, Mick S, Suri RM. The specialty of mitral valve repair. *J Am Coll Cardiol*. 2017;69(19):2407-2409. https://doi.org/10.1016/J.JACC.2017.01.059
11. Anyanwu AC, Adams DH. Benchmarking mitral valve repair: defining standards for surgical and percutaneous treatment of severe mitral regurgitation. *J Am Coll Cardiol*. 2023;81(7):649-652. https://doi.org/10.1016/J.JACC.2023.01.001
12. Badhwar V, Rankin JS, He X, et al. The Society of Thoracic Surgeons Mitral Repair/Replacement Composite Score: a report of the Society of Thoracic Surgeons Quality Measurement Task Force. *Ann Thorac Surg*. 2016;101(6):2265-2271. https://doi.org/10.1016/J.ATHORACSUR.2015.11.049
13. Zoghbi WA, Adams D, Bonow RO, et al. Recommendations for noninvasive evaluation of native valvular regurgitation: a report from the American Society of Echocardiography developed in collaboration with the Society for Cardiovascular Magnetic Resonance. *J Am Soc Echocardiogr*. 2017;30(4):303-371. https://doi.org/10.1016/J.ECHO.2017.01.007
14. Lown B, Wolf M. Approaches to sudden death from coronary heart disease. *Circulation*. 1971;44(1):130-142. https://doi.org/10.1161/01.CIR.44.1.130
15. Doherty JU, Kort S, Mehran R, et al. ACC/AATS/AHA/ASE/ASNC/HRS/SCAI/SCCT/SCMR/STS 2017 appropriate use criteria for multimodality imaging in Valvular Heart Disease. *J Am Soc Echocardiogr*. 2018;31(4):381-404. https://doi.org/10.1016/j.echo.2017.08.012
16. Dweck MR, Abgral R, Trivieri MG, et al. Hybrid magnetic resonance imaging and positron emission tomography with fluorodeoxyglucose to diagnose active cardiac sarcoidosis. *JACC Cardiovasc Imaging*. 2018;11(1):94-107. https://doi.org/10.1016/J.JCMG.2017.02.021
17. Miller MA, Adams DH, Pandis D, et al. Hybrid positron emission tomography/magnetic resonance imaging in arrhythmic mitral valve prolapse. *JAMA Cardiol*. 2020;5(9):1000-1005. https://doi.org/10.1001/jamacardio.2020.1555
18. Miller MA, Devesa A, Robson PM, et al. Arrhythmic mitral valve prolapse with only mild or moderate mitral regurgitation: characterization of myocardial substrate. *JACC Clin Electrophysiol*. 2023;9(8):1709-1716. https://doi.org/10.1016/J.JACEP.2023.04.011
19. Carpentier A, Adams DH, Filsoufi F. *Carpentier's Reconstructive Valve Surgery: From Valve Analysis to Valve Reconstruction*. 1st ed. Saunders/Elsevier; 2010.
20. Care everywhere | HIMSS. Accessed January 22, 2024. https://www.himss.org/resource-environmental-scan/care-everywhere
21. Badhwar V, Peterson ED, Jacobs JP, et al. Longitudinal outcome of isolated mitral repair in older patients: results from 14,604 procedures performed from 1991 to 2007. *Ann Thorac Surg*. 2012;94(6):1870-1879. https://doi.org/10.1016/J.ATHORACSUR.2012.05.105
22. Gammie JS, Chikwe J, Badhwar V, et al. Isolated mitral valve surgery: the Society of Thoracic Surgeons Adult Cardiac Surgery Database analysis. *Ann Thorac Surg*. 2018;106(3):716-727. https://doi.org/10.1016/J.ATHORACSUR.2018.03.086
23. David TE, David CM, Tsang W, Lafreniere-Roula M, Manlhiot C. Long-term results of mitral valve repair for regurgitation due to leaflet prolapse. *J Am Coll Cardiol*. 2019;74(8):1044-1053. https://doi.org/10.1016/J.JACC.2019.06.052
24. Chikwe J, Toyoda N, Anyanwu AC, et al. Relation of mitral valve surgery volume to repair rate, durability, and survival. *J Am Coll Cardiol*. 2017;69(19):2397-2406. https://doi.org/10.1016/J.JACC.2017.02.026
25. Anyanwu AC. The vagaries of patient selection in cardiovascular surgery. *J Thorac Cardiovasc Surg*. 2016;152(3):842-846. https://doi.org/10.1016/J.JTCVS.2016.03.032
26. Likosky DS, Goldberg JB, Discipio AW, et al. Variability in surgeons' perioperative practices may influence the incidence of low-output failure after coronary artery bypass grafting surgery. *Circ Cardiovasc Qual Outcomes*. 2012;5(5):638-644. https://doi.org/10.1161/CIRCOUTCOMES.112.967091
27. Alqarawi W, Birnie DH, Burwash IG. Mitral valve repair results in suppression of ventricular arrhythmias and normalization of repolarization abnormalities in mitral valve prolapse. *HeartRhythm Case Rep*. 2018;4(5):191. https://doi.org/10.1016/J.HRCR.2018.02.012
28. Delling FN, Aung S, Vittinghoff E, et al. Antemortem and post-mortem characteristics of lethal mitral valve prolapse among all countywide sudden deaths. *JACC Clin Electrophysiol*. 2021;7(8):1025-1034. https://doi.org/10.1016/J.JACEP.2021.01.007
29. Marra MP, Basso C, De Lazzari M, et al. Morphofunctional abnormalities of mitral annulus and arrhythmic mitral valve prolapse. *Circ Cardiovasc Imaging*. 2016;9(8):e005030. https://doi.org/10.1161/CIRCIMAGING.116.005030
30. Kitkungvan D, Nabi F, Kim RJ, et al. Myocardial fibrosis in patients with primary mitral regurgitation with and without prolapse. *J Am Coll Cardiol*. 2018;72(8):823-834. https://doi.org/10.1016/j.jacc.2018.06.048
31. Sabbag A, Essayagh B, Barrera JDR, et al. EHRA expert consensus statement on arrhythmic mitral valve prolapse and mitral annular disjunction complex in collaboration with the ESC Council on valvular heart disease and the European Association of Cardiovascular Imaging endorsed by the Heart Rhythm Society, by the Asia Pacific Heart Rhythm Society, and by the Latin American Heart Rhythm Society. *Europace*. 2022;24(12):1981-2003. https://doi.org/10.1093/EUROPACE/EUAC125
32. Essayagh B, Mantovani F, Benfari G, et al. Mitral annular disjunction of degenerative mitral regurgitation: three-dimensional evaluation and implications for mitral repair. *J Am Soc Echocardiogr*. 2022;35(2):165-175. https://doi.org/10.1016/J.ECHO.2021.09.004
33. Kitkungvan D, Yang EY, El Tallawi KC, et al. Extracellular volume in primary mitral regurgitation. *JACC Cardiovasc Imaging*. 2021;14(6):1146-1160. https://doi.org/10.1016/J.JCMG.2020.10.010
34. Bui AH, Roujol S, Foppa M, et al. Diffuse myocardial fibrosis in patients with mitral valve prolapse and ventricular arrhythmia. *Heart*. 2017;103(3):204-209. https://doi.org/10.1136/HEARTJNL-2016-309303
35. Delgado V, Podlesnikar T. Focal replacement and diffuse fibrosis in primary mitral regurgitation: a new piece to the puzzle. *JACC Cardiovasc Imaging*. 2021;14(6):1161-1163. https://doi.org/10.1016/J.JCMG.2020.11.005
36. Yang LT, Ahn SW, Li Z, et al. Mitral valve prolapse patients with less than moderate mitral regurgitation exhibit early cardiac chamber remodeling. *J Am Soc Echocardiogr*. 2020;33(7):815-825.e2. https://doi.org/10.1016/J.ECHO.2020.01.016
37. Grigioni F, Enriquez-Sarano M, Ling LH, et al. Sudden death in mitral regurgitation due to flail leaflet. *J Am Coll Cardiol*. 1999;34(7):2078-2085.
38. Edwards NC, Moody WE, Yuan M, et al. Quantification of left ventricular interstitial fibrosis in asymptomatic chronic primary degenerative mitral regurgitation. *Circ Cardiovasc Imaging*. 2014;7(6):946-953. https://doi.org/10.1161/CIRCIMAGING.114.002397
39. Otto C, Nishimura R, Bonow R, et al. 2020 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 Am Coll Cardiol*. 2021;77(4):e25-e197. https://doi.org/10.1016/J.JACC.2020.11.018
40. Evenson KR, Lamar Welch VL, Cascio WE, Simpson RJ. Validation of a short rhythm strip compared to ambulatory ECG monitoring for ventricular ectopy. *J Clin Epidemiol*. 2000;53(5):491-497. https://doi.org/10.1016/S0895-4356(99)00190-0

Key Words: arrhythmic mitral valve prolapse, complex ventricular, degenerative mitral valve disease, malignant mitral prolapse, mitral regurgitation, mitral repair outcomes, recurrent ventricular arrhythmia, sudden cardiac death, surgical mitral repair, ventricular ectopy

E-Reference

E1. Malyshev Y, Miller MA. Catheter ablation of arrhythmic mitral valve prolapse: should we be MAD? No, quite the opposite. *JACC Clin Electrophysiol*. 2023; 9(8):1276-1278. https://doi.org/10.1016/J.JACEP.2023.05.008

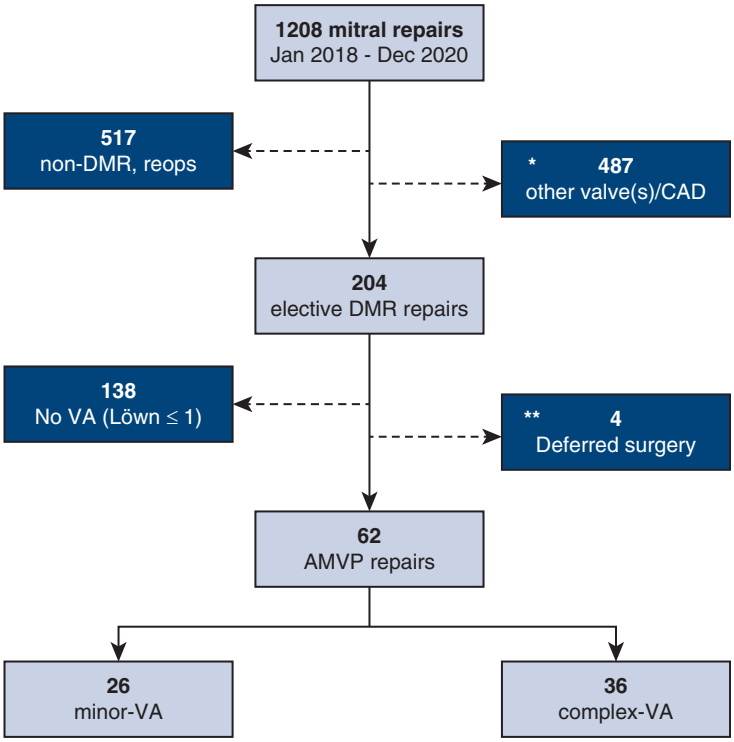

FIGURE E1. Study population flow gram. *Excluded cases with concomitant moderate or greater aortic/pulmonary valve disease, significant CAD (including previous coronary intervention), or need for concomitant CABG. **Patients with AMVP deferred mitral surgery because of absent clinical symptoms. *CAD*, Coronary artery disease; *DMR*, degenerative mitral regurgitation; *AMVP*, arrhythmic mitral valve prolapse; *VA*, ventricular arrhythmia; *CABG*, coronary artery bypass graft surgery.

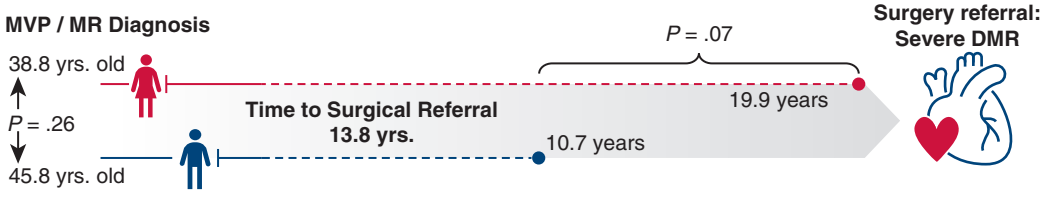

FIGURE E2. Surgical referral practice patterns. The median time to surgical referral was 13.8 years from initial diagnosis of mitral prolapse or regurgitation (whichever came first). Female patients were diagnosed relatively earlier than male patients but were referred later for surgical mitral repair. *MVP*, Mitral valve prolapse; *MR*, mitral regurgitation; *DMR*, degenerative mitral regurgitation.

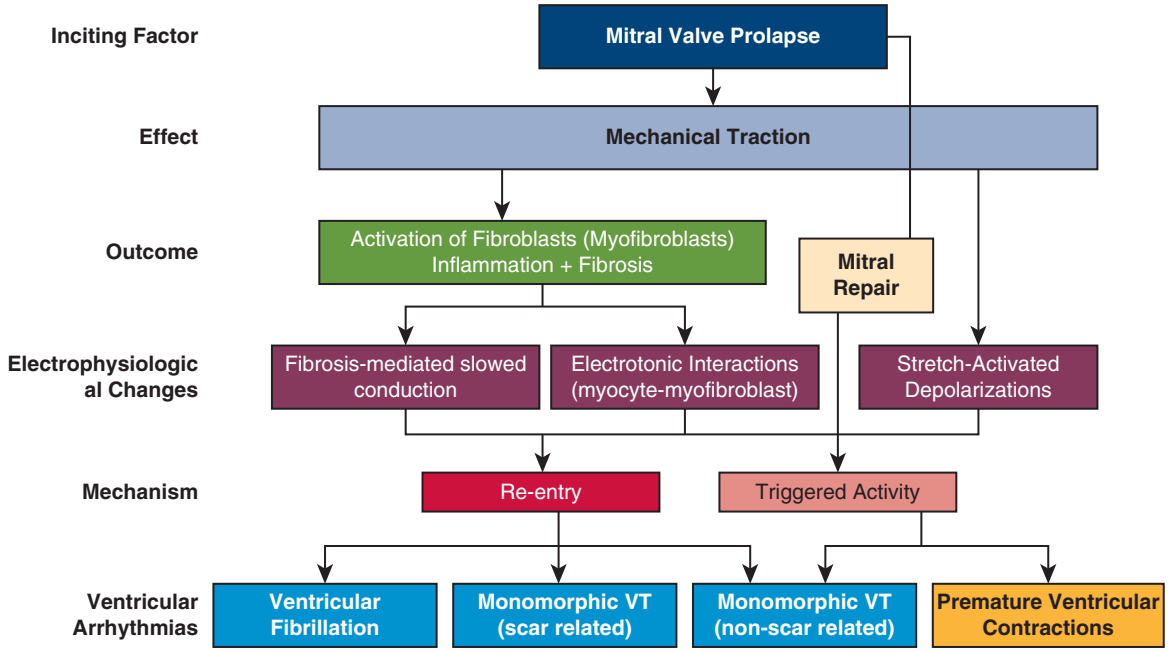

FIGURE E3. Mechanistic role of mitral repair in VA suppression. Suggested downstream effect of stretch-stress activation of myocardial inflammatory response due to traction from excess leaflet motion in mitral valve prolapse.[E1] The resulting electrophysiologic alterations in myocardial steady-state favor an environment of electrical instability (ie, stretch-activated depolarizations; altered electrotonic interactions) and the development of ventricular arrhythmias. Corrective mitral valve repair surgery is thought to abolish the VA mechanism related to triggered activity by alleviating the prolapse excess traction and associated stretch-activated inflammatory myocardial response by restoring physiologic mitral valve anatomy and function, thereby normalizing the intracavitary forces. *VT*, Ventricular tachycardia; *VA*, ventricular arrhythmia.

TABLE E1. Risk factors related to recurrent VA at 1 year after mitral repair surgery

	R^2	OR (95% CI)	AUC	*P*
Demographics and comorbidities				
Age, y	0.01	0.98 (0.93-1)	0.58	.43
Age at MR/MVP diagnosis, y	0.043	0.97 (0.94-1)	0.64	.11
Age at VA diagnosis, y	0.026	0.97 (0.92-1.02)	0.61	.21
Symptoms (NYHA II-III)	0.005	0.71 (0.22-2.27)	0.54	.56
Female	0.003	1.29 (0.4-4.15)	0.53	.67
Familial MVP	0.001	0.95 (2.56-3.5)	0.51	.94
Hypertension	0.1	4.85 (1.3-17.6)	0.69	.016
Diabetes mellitus	0.01	3.29 (0.19-56)	0.52	.42
Smoking	0.0006	1.23 (0.12-13.2)	0.51	.86
Obstructive sleep apnea	0.002	1.6 (0.14-19.1)	0.51	.71
Secondary PHT	0.01	0.59 (0.16-2.1)	0.56	.42
Atrial fibrillation/flutter	0.0002	0.93 (0.22-3.9)	0.51	.92
BP systolic	0.044	1.03 (0.99-1.06)	0.61	.09
BP diastolic	0.023	1.04 (0.98-1.11)	0.57	.24
Pulse pressure, mm Hg	0.03	1.03 (0.99-1.07)	0.57	.17
Antiarrhythmic therapy	0.03	2.44 (0.75-7.98)	0.61	.15
Serum K+, mEq/L	0.018	3.27 (0.37-28.6)	0.56	.29
BNP, pg/mL	0.01	0.99 (0.98-1)	0.56	.49
Rest echocardiography				
LV EF, %	0.022	0.95 (0.86-0.24)	0.58	.24
LVEDDi, cm/m^2	0.0005	1.15 (0.23-5.8)	0.51	.86
LVESDi, cm/m^2	0.001	0.77 (0.1-5.9)	0.54	.79
LV mass(i), g/m^2 (range)	0.00008	0.99 (0.97-1.02)	0.50	.94
RWT	0.0008	0.06 (0-194)	0.57	.50
LV wall stress ($\times 10^3$), dyn/cm^2 (SD)	0.002	0.99 (0.97-1.02)	0.56	.73
Peak GLS, %	0.01	0.93 (0.78-1.1)	0.52	.39
LV mechanical dispersion, ms	0.005	0.99 (0.98-1.01)	0.55	.59
LAVi, mL/m^2	0.021	0.98 (0.95-1.01)	0.59	.31
PASP, mm Hg	0.052	0.94 (0.87-1.01)	0.66	.10
MV E/A	0.00009	1.03 (0.49-2.15)	0.53	.94
MV E/e'	0.022	0.92 (0.79-1.08)	0.60	.30
Bileaflet prolapse	0.0006	1.13 (0.33-3.87)	0.51	.84
Cardiac MRI				
LV scar/fibrosis (LGE+)	0.01	1.6 (0.34-7.64)	0.55	.56
Hybrid PET/MRI				
LV inflammation (FDG+)	0.11	–	0.6	1
Ventricular arrhythmia and ECG characteristics				
MR diagnosis to VA, y	0.01	1.02 (0.97-1.7)	0.61	.51
VA diagnosis to MR, y	0.006	1.07 (0.72-1.6)	0.54	.73
Preoperative VA burden, % (range)	0.06	1.05 (0.99-1.11)	0.70	.11
Preoperative VA complex (Lown $\geq$3)	0.18	15.91 (1.9-131)	0.73	.01
VA-related syncope	0.06	4.2 (1.01-17.5)	0.61	.047
History of sudden death	0.08	11.5 (1.1-121)	0.59	.04
Heart rate, beats/min	0.003	0.99 (0.95-1.03)	0.52	.68
QTc, ms	0.002	1 (0.98-1.03)	0.52	.74
Prolonged QTc	0.011	0.59 (0.16-2.12)	0.56	.42
QRS, ms (range)	0.073	1.06 (1-1.13)	0.66	.041
Nonspecific ST-T	0.014	1.9 (0.51-6.66)	0.56	.35
Repolarization abnormalities	0.007	1.71 (0.37-7.87)	0.54	.49
Inverted/biphasic T-waves	0.068	3.54 (1.1-11.8)	0.65	.04
Conduction delay (LV or AV)	0.14	6.55 (1.84-23.3)	0.72	.004
Fascicular block	0.11	5.98 (1.6-22.6)	0.67	.008
LVH-ECG voltage criteria	0.005	0.46 (0.42-5.13)	0.54	.56

(Continued)

TABLE E1. Continued

	R^2	OR (95% CI)	AUC	*P*
Operative characteristics				
MR diagnosis to surgery, y	0.03	1.03 (0.99-1.07)	0.64	.17
STS PROM, %	0.0016	1.34 (0.21-8.48)	0.56	.75
Flail (chordal rupture/elongation)	0.003	0.78 (0.24-2.5)	0.53	.67
Segments repaired, n (range)	0.0001	0.98 (0.62-1.6)	0.51	.93
Repair complexity score	0.001	0.97 (0.78-1.19)	0.51	.78
Mitral ring size, mm (IQR)	0.0035	0.96 (0.81-1.14)	0.56	.64
CPB, min	0.008	0.99 (0.97-1.01)	0.53	.488
Crossclamp	0.0036	0.99 (0.97-1.02)	0.52	.648
ICU stay, d	0.065	0.54 (0.26-1.15)	0.62	.112
Hospital stay, d	0.0001	0.86 (0.02-39)	0.66	.937
MAE	0.0009	0.77 (0.08-7.45)	0.51	.819
Postoperative transient VT/PVC's	0.0034	1.42 (0.32-6.4)	0.53	.641

OR, Odds ratio; *CI*, confidence interval; *AUC*, area under the curve; *MR*, mitral regurgitation; *MVP*, mitral valve prolapse; *NYHA*, New York Heart Association; *MVP*, mitral valve prolapse; *PHT*, pulmonary hypertension; *BP*, blood pressure; *BNP*, brain natriuretic peptide; *LV*, left ventricle/-cular; *EF*, ejection fraction; *EDDi*, end-diastolic diameter index; *ESDi*, end-systolic diameter index; *SD*, standard deviation; *GLS*, global longitudinal strain; *LAVi*, left atrial volume index; *PASP*, pulmonary arterial systolic pressure; *MV*, mitral valve; *MRI*, magnetic resonance imaging; *LGE*, late gadolinium enhancement; *PET*, positron emission tomography; *FDG*, fluorodeoxyglucose; *ECG*, electrocardiogram; *MR*, mitral regurgitation; *VA*, ventricular arrhythmia; *AV*, atrioventricular; *CAD*, coronary artery disease; *LVH*, left ventricular hypertrophy; *STS PROM*, Society of Thoracic Surgeons Predicted Risk Of Mortality; *IQR*, interquartile range; *CPB*, cardiopulmonary bypass; *ICU*, intensive care unit; *MAE*, major adverse events; *VT*, ventricular tachycardia; *PVC*, premature ventricular contraction.

TABLE E2. Patient, imaging, VA, and operative characteristics stratified by VA recurrence

n (%)/median (IQR)	1-y follow-up (N = 54)	No VA recurrence (n = 41)	Recurrent VA (n = 13)	*P*
Demographics and comorbidities				
Age, y (IQR)	59 (51-64)	59 (50.3-65)	59 (50-63.3)	.785
Age at MR/MVP diagnosis, y	41.7 (27.5-52.5)	41.4 (29.6-54.8)	43 (19.5-47.3)	.379
Age at VA diagnosis, y	50.3 (37.5-57.8)	51 (37.3-58.7)	45.5 (37-55.6)	.407
Symptoms functional class				.229
NYHA I	24 (44.4)	17 (41.5)	7 (53.8)	
NYHA II	25 (46.3)	19 (46.3)	6 (46.2)	
NYHA III	5 (9.3)	5 (12.2)	-	
Female	21 (38.9)	15 (36.6)	6 (46.2)	.541
Familial MVP	16 (29.6)	5 (19.2)	12 (33.3)	.223
Hypertension	25 (46.3)	15 (36.6)	10 (76.9)	.012
Diabetes mellitus	2 (3.7)	1 (2.4)	1 (2.7)	.387
Chronic lung disease	3 (5.6)	3 (7.3)	–	.320
Smoking	13 (24.1)	8 (19.5)	5 (38.5)	.285
Obstructive sleep apnea	3 (5.6)	2 (4.9)	1 (7.7)	.702
Secondary PHT	19 (35.2)	15 (36.6)	4 (30.8)	.705
Atrial fibrillation/flutter	13 (24.1)	10 (24.4)	3 (23.1)	.924
BP systolic	130 (118-137)	128 (116-133.3)	132 (121-149.8)	.129
BP diastolic	73.9 (68-81)	74 (64.8-80)	74 (70-87.5)	.105
Pulse Pressure, mm Hg	53.5 (44-64)	53 (46.3-60)	60 (43-75)	.510
Anti-arrhythmic therapy (n, 50)	35/50 (70)	23/37 (74)	12/13 (92.3)	.043
Diuretic therapy	7 (13)	4 (9.8)	3 (23.1)	.217
Serum K+, mEq/L	4.2 (4.1-4.4)	4.2 (4.1-4.4)	4.3 (4.1-4.5)	.567
BNP, pg/mL	62.7 (32.6-119.5)	64.7 (31.2-125.7)	45.8 (29.6-106.2)	.504
Imaging echo				
Resting echocardiography	54 (100)	41 (100)	13 (100)	–
LV EF, %	63 (60-65)	63 (60-67)	60 (57.3-63.3)	.116
LVEDd, cm	5.5 (5.1-5.8)	5.5 (5-5.9)	5.53 (5.3-5.8)	.641
LVEDDi, cm/m^2	2.92 (2.66-3.21)	2.92 (2.66-3.21)	3 (2.65-3.16)	.754
LVEDs, cm	3.5 (3.1-3.9)	3.38 (3.1-3.9)	3.6 (3.3-3.85)	.436
LVESDi, cm/m^2	1.85 (1.66-2.04)	1.81 (1.67-2.02)	1.85 (1.66-2.06)	.557
LV mass(i), g/m^2 (range)	117.5 (100-131.6)	118.6 (97.7-131.7)	116.9 (102.4-131.4)	.765
LV wall stress ($\times 10^3$), dyn/cm^2 (SD)	68.98 (51.2-86.4)	74.01 (50.4-86.7)	66.3 (60.3-81.9)	.832
Peak GLS, %	−25.5 (−26.8 to −23.5)	−25.8 (−26.7 to −22.8)	−24.9 (−27.8 to −23.9)	.895
LV mechanical dispersion, ms	52.2 (34.4-82.8)	55.4 (33.2-91.2)	51.4 (38.8-69)	.634
LAVi, mL/m^2	61.5 (54.2-91.1)	64.6 (53.3-91.8)	59.6 (57.3-72.9)	.585
PASP, mm Hg	27.5 (24-38.6)	27 (24.9-39.3)	28 (23.6-36.3)	.557
MV E/A	1.47 (1.13-1.79)	1.44 (1.1-2)	1.54 (1.2-1.7)	.764
MV E/e'	9.95 (7.3-13.5)	10.8 (9.1-14.8)	7.8 (7.2-10.1)	.055
Diastolic filling time, ms	515 (423-616.8)	513.5 (404-620.5)	526 (451.6-610.3)	.604
Bileaflet prolapse	37 (68.5)	28 (68.3)	9 (69.2)	.949
Bileaflet prolapse—female	18 (33.3)	13 (31.7)	5 (38.5)	.656
Imaging-PET/MRI				
Cardiac MRI	33 (61.1)	24 (58.5)	9 (69.2)	.495
LV scar/fibrosis (LGE+)	22 (68.7)	16 (69.6)	6 (66.7)	.876
Preoperative hybrid PET/MRI	22 (40.7)	17 (41.5)	5 (38.5)	.849
LV inflammation (FDG+)	19 (86.4)	14 (82.4)	5 (100)	.323
VA and ECG				
MR diagnosis to VA, y	9.9 (5-21)/(n = 38)	1.7 (4.8-24)/(n = 27)	8.4 (5-17.5)/(n = 11)	.847
VA diagnosis to MR, y	2 (1.95-4)/(n = 16)	2 (2-3)/(n = 14)	5 (1-9)/(n = 2)	.935
Ambulatory rhythm monitor	43 (79.6)	32 (78)	11 (84.6)	.612
VA burden, % (range)	20 (0.01-42)/(n = 11)	–	20 (0.01-42)/(n = 11)	–
Bigeminy	24 (39.3)	13 (32.5)	7 (53.8)	.172
Pleiomorphic PVCs	21 (33.9)	10 (24.4)	8 (61.5)	.014

(Continued)

TABLE E2. Continued

n (%)/median (IQR)	1-y follow-up (N = 54)	No VA recurrence (n = 41)	Recurrent VA (n = 13)	*P*
Ventricular couplets	26 (41.9)	17 (41.5)	7 (53.8)	.438
Ventricular tachycardia	30 (48.4)	18 (43.9)	12 (92.3)	.002
VA-related syncope	10 (18.5)	6 (14.6)	4 (30.8)	.196
Sudden cardiac arrest	4 (7.4)	1 (2.4)	3 (23.1)	.014
ICD in situ	8 (14.8)	5 (12.2)	3 (23.1)	.340
Heart rate, bpm	65.5 (59-79)	64 (59-79)	70 (59.8-81.3)	.544
Sinus bradycardia	15 (27.8)	12 (29.3)	3 (23.1)	.667
QTc, m	434.5 (418-447)	428 (417.3-447)	438 (427.3-446.5)	.302
QTc (age-adj), ms	433.3 (431-434.7)	433.3 (430.7-435)	433.3 (430.66-434.5)	.785
Prolonged QTc	19 (35.2)	15 (36.6)	4 (30.78)	.705
Prolonged QTc, ms	453 (446.3-457)	453 (446.3-456.5)	459 (447-471.5)	.582
Prolonged QTc (age-adj), ms	434.1 (432.8-434.9)	434.1 (432.8-434.9)	433.9 (430.9-435.1)	.841
QRS, ms (range)	98 (88-104)	94 (86-102)	100 (93.5-107.5)	.043
Nonspecific ST-T	11 (20.4)	7 (17.1)	4 (30.8)	.289
Repolarization abnormalities	8 (14.8)	6 (124.6)	2 (15.4)	.948
Inverted/biphasic T-waves	23 (42.6)	16 (39)	7 (53.8)	.351
Infarct pattern	23 (37.1)	8 (30.8)	15 (41.7)	.385
T-wave inversion—inferior	7 (30.4)	4 (25)	3 (42.9)	.402
T-wave inversion—anterior	16 (69.6)	12 (75)	4 (57.1)	
Conduction delay	21 (38.9)	13 (31.7)	8 (61.5)	.057
1° AV block	8 (14.8)	5 (12.2)	3 (23.1)	.340
Fascicular block	13 (24.1)	7 (17.1)	6 (46.2)	.034
LBBB	1 (7.7)	1 (14.3)	–	.354
RBBB	12 (92.3)	6 (85.7)	6 (100)	
LVH-ECG voltage criteria	16 (29.6)	13 (31.7)	3 (23.1)	.556
Surgical referral and intraoperative				
MR diagnosis to surgery, y	14 (3.6-24.8)	10.8 (2.7-23.9)	18.9 (13-25.6)	.178
Surgical referral trigger				
Dyspnea/exercise tolerance	25 (46.3)	19 (46.3)	6 (46.2)	.503
MR severity progression	10 (18.5)	7 (17.1)	3 (23.1)	
Palpitations	10 (18.5)	7 (17.1)	3 (23.1)	
Worsening LV dimensions/EF	7 (13)	7 (17.1)	–	
Operative indication				
ACC/AHA class I	38 (70.4)	31 (75.6)	7 (53.8)	.138
ACC/AHA class IIa	16 (29.6)	10 (24.4)	6 (46.2)	
STS PROM, %	0.43 (0.27-0.74)	0.395 (0.25-0.74)	0.52 (0.35-0.62)	.402
Prolapse phenotype				
Barlow—bileaflet	37 (68.5)	27 (65.9)	10 (76.9)	.758
Barlow—forme-fruste	14 (25.9)	11 (26.8)	3 (23.1)	
Fibroelastic deficiency	2 (3.7)	2 (4.9)	–	
Anterior leaflet prolapse	1 (1.9)	1 (2.4)	–	
Flail (chordal rupture/elongation)	32 (59.3)	25 (61)	7 (53.8)	.652
Segments repaired, n (range)	2 (1-6)	2 (1-6)	2 (1-4)	.720
Repair complexity score, n (range)	3 (1-13)	2 (1-13)	3 (1-5)	.975
Simple	17 (31.5)	13 (31.7)	4 (30.8)	.893
Intermediate	23 (42.6)	18 (43.9)	5 (38.5)	
Complex	14 (25.9)	10 (24.4)	4 (30.8)	
Mitral annuloplasty size, mm	36 (34-38)	36 (32-38)	34 (34-36)	.466
Mitral annuloplasty type				
Flexible band	27 (50)	18 (43.9)	9 (69.2)	.195
Remodeling ring	27 (50)	23 (56.1)	3 (30.8)	
Concomitant procedures				
Tricuspid valve repair	44 (81.5)	35 (85.4)	9 (69.2)	.196
LAA exclusion	16 (29.6)	13 (31.7)	3 (23.1)	.556
AF cryo-maze	14 (25.9)	11 (26.8)	3 (23.1)	.789

(Continued)

TABLE E2. Continued

n (%)/median (IQR)	1-y follow-up (N = 54)	No VA recurrence (n = 41)	Recurrent VA (n = 13)	*P*
PFO closure	7 (13)	5 (12.2)	2 (15.4)	.768
ICD leads exchange	2 (3.7)	1 (2.4)	1 (7.7)	.387
CPB, min (IQR)	118.5 (95-132)	120 (94.5-134.5)	110 (96-125.5)	.357
Crossclamp, min	88.5 (70-103.5)	95 (69.3-110)	85 (79-96.8)	.459
ICU stay, d	1.1 (0.9-2.1)	1.1 (0.9-2.8)	0.9 (0.8-1.4)	.166
Hospital stay, d	7 (5-9)	7 (5-9.3)	6 (5-8)	.425
Discharge antiarrhythmic				
Beta-blocker	29 (53.7)	19 (46.3)	10 (76.9)	.072
Beta-blocker+ amiodarone	14 (25.9)	11 (26.8)	3 (23.1)	
Beta-blocker CI	11 (20.4)	11 (26.8)	–	
Operative outcomes				
MAE (at 30 d)	4 (7.4)	3 (7.3)	1 (7.7)	.964
Operative death	–	–	–	–
MI	–	–	–	–
Stroke	1 (1.9)	1 (2.4)	–	.573
Acute kidney injury	–	–	–	–
Respiratory failure	3 (5.6)	2 (4.9)	1 (7.7)	.702
New PPM	–	–	–	–
MAE (at 1 y)	–	–	–	–
Recurrent MR >1+	–	–	–	–
Cardiac-related readmission	–	–	–	–
Cardiac reintervention (any)	–	–	–	–

IQR, Interquartile range; *VA*, ventricular arrhythmia; *MR*, mitral regurgitation; *MVP*, mitral valve prolapse; *NYHA*, New York Heart Association; *PHT*, pulmonary hypertension; *BP*, blood pressure; *BNP*, brain natriuretic peptide; *LV*, left ventricle/-cular; *EF*, ejection fraction; *EDDi*, end-diastolic diameter index; *ESDi*, end-systolic diameter index; *SD*, standard deviation; *GLS*, global longitudinal strain; *LAVi*, left atrial volume index; *PASP*, pulmonary arterial systolic pressure; *MV*, mitral valve; *PET*, positron emission tomography; *MRI*, magnetic resonance imaging; *LGE*, late gadolinium enhancement; *FDG*, fluorodeoxyglucose; *ECG*, electrocardiogram; *MR*, mitral regurgitation; *PVCs*, premature ventricular contractions; *ICD*, implantable cardioverter/defibrillator; *AV*, atrioventricular; *LBBB*, left bundle branch block; *RBBB*, right bundle branch block; *LVH*, left ventricular hypertrophy; *ACC*, American College of Cardiology; *AHA*, American Heart Association; *STS PROM*, Society of Thoracic Surgeons Predicted Risk Of Mortality; *LAA*, left atrial appendage; *AF*, atrial fibrillation; *PFO*, patent foramen ovale; *CI*, contraindication; *MAE*, major adverse events; *MI*, myocardial infarction; *PPM*, permanent pacemaker.