

The prognostic importance of the right ventricle for patients with mitral regurgitation undergoing surgical treatment: A speckle tracking study

Maria Concetta Pastore^{a,*}, Federica Marrese^a, Andrea Marchese^a, Lorenzo Tanzi^a,
Andrea Stefanini^a, Antonio Capolongo^b, Giulia Elena Mandoli^a, Ilenia Pennisi^a,
Martina Rizzo^c, Veronica Lorenz^c, Giuseppe Alba^d, Gianfranco Montesi^c, Luna Cavigli^a,
Flavio D'Ascenzi^a, Marta Focardi^a, Serafina Valente^a, Ottavio Alfieri^e, Matteo Cameli^a

^a Department of Medical Biotechnologies, Division of Cardiology, University of Siena, Siena, Italy

^b Department of Translational Medical Sciences, University of Campania "Luigi Vanvitelli", Naples, Italy

^c Department of Cardiothoracic and Vascular Disease, Division of Cardiac Surgery, University of Siena, Siena, Italy

^d Department of Vascular Surgery, University of Siena, Siena, Italy

^e Cardiac Surgery Unit, IRCCS San Raffaele University Hospital, Via Olgettina 60, Milan 20132, Italy

ARTICLE INFO

Keywords:

Mitral regurgitation
Surgery
Left atrial
Right ventricular
Speckle tracking
Prognosis

ABSTRACT

Background: A careful preoperative evaluation of patients with mitral regurgitation (MR) is pivotal to optimize the timing of intervention and clinical outcome. The aim of this study was to evaluate preoperative prognostic parameters, among basic and speckle tracking echocardiography (STE), in patients undergoing MR surgery.

Methods: We prospectively enrolled patients with severe MR who underwent preoperative clinical, biochemical and echocardiographic evaluation, before mitral valve surgery. After surgery, patients were followed to investigate clinical outcome. The primary endpoint was a composite of heart failure hospitalizations and all cause-mortality, the secondary endpoint was to identify the best predictors of postoperative functional capacity assessed by New York heart association (NYHA) class.

Results: The final study cohort consisted of 110 patients with a mean age of 64 ± 13 years, 59% male. All strain parameters were reduced, while myocardial work (MW) showed normal values. Median follow-up was 17 (10–29) months. The primary endpoint occurred in 10 patients. Two echocardiographic predictors for the primary endpoint were global peak atrial longitudinal strain (PALS) $\leq 21.5\%$ and free wall right ventricular longitudinal strain (fwRVLS) $\geq -22\%$ with ROC curves. The study population was then divided into 3 groups (Group 1, $n = 32$: PALS $> 21.5\%$ and fwRVLS $< -22\%$, Group 2, $n = 46$: either global PALS or fwRVLS reduced, Group 3, $n = 32$: PALS $\leq 21.5\%$ and fwRVLS $\geq -22\%$). Kaplan–Meier curves showed good risk stratification of the composite endpoint across the three groups. Global wasted work (GWW) was an independent predictor of symptoms persistence (NYHA class $> II$) at follow-up.

Conclusions: STE, particularly with the combination of left atrial and right ventricular strain analysis, can provide additional prognostic value for the preoperative evaluation of patients with MR referred for surgery.

1. Introduction

Mitral regurgitation (MR) is the second most common valvular heart disease (VHD) [1]. Primary or degenerative etiology is the first cause of MR in developed Countries. Cardiac surgery is the most common treatment for primary MR; however, it carries a considerable risk of postoperative complications, thus it is important to provide a careful preoperative evaluation for the selection of candidates and ideal timing

for surgery [2]. In fact, the role of left ventricular (LV) dilation and dysfunction as criteria for surgery are extremely debated, since many authors believe that the occurrence of LV dysfunction represents a late point in the natural history of the disease when surgery may be futile. In fact, as the hemodynamic overload caused by MR affects first the left atrium (LA) and then the left ventricle, the study of the LA has been proposed to precede LV assessment as surgical criteria and prognostic stratification [2,3]. Moreover, the evaluation of possible right

* Corresponding author at: Department of Medical Biotechnologies, Division of Cardiology, University of Siena, Viale Bracci 1, Siena, Italy.

E-mail address: mariaconce.pastore@unisi.it (M.C. Pastore).

<https://doi.org/10.1016/j.ijcard.2026.134681>

Received 7 May 2026; Received in revised form 11 July 2026; Accepted 17 July 2026

Available online 19 July 2026

0167-5273/© 2026 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

ventricular (RV) systolic function should not be neglected, both since RV dysfunction is common in patients with chronic MR undergoing surgery as a direct and indirect consequence of chronic volume overload, and since RV dysfunction may occur after MV surgery due to prolonged extracorporeal circulation time and pericardiotomy and, therefore, a damaged RV at baseline may not manage to front the changes in hemodynamics after intervention [3].

Speckle tracking echocardiography (STE) has shown to provide early markers of cardiac damage compared to basic echocardiography, which may be used both for diagnosis and risk stratification [2].

Global Longitudinal Strain (GLS) is an increasingly used measure to assess cardiac systo-diastolic function as it has shown to be a more sensitive marker than conventional echocardiographic parameters [4]. Global peak atrial longitudinal strain (PALS) by STE has been associated with survival and functional capacity as assessed by New York heart association (NYHA) [5] class and Borg scale [6] after mitral surgery. Some authors [7,8] demonstrated that global peak atrial longitudinal and contraction strain (PALS and PACS) were associated with surgical timing, surgery-free survival and postoperative atrial fibrillation in patients with mitral valve prolapse and moderate-to-severe MR. On the other hand, the evidence on the use of RV strain in this setting remains poor. Myocardial work (MW) is a new tool of STE software which allows to derive less load-dependent values of LV function based on pressure-strain loops, easy obtainable integrating LV strain calculation with blood pressure measured at the time of exam. This is still matter of research, however, has shown potential value in many clinical settings, among which MR, in which it showed a gradual worsening according to severity [9].

Consequently, this study was conducted with the aim of identifying prognostic predictors among STE and MW parameters in patients undergoing mitral surgery for severe MR.

2. Material and methods

Consecutive patients with severe degenerative MR requiring cardiac surgery, who underwent surgery between 2020 and 2022 at the Santa Maria alle Scotte Hospital in Siena, were prospectively enrolled. Surgical procedures comprised isolated mitral valve repair, mitral valve replacement, mitral valve repair with concomitant coronary artery bypass grafting (CABG), and mitral valve repair with concomitant tricuspid valve repair. Mitral valve replacement was performed when valve anatomy precluded a durable repair, and concomitant CABG and tricuspid repair followed standard surgical indications. Patients with non-sinus rhythm at the time of echocardiography, previous cardiac surgery or other severe VHD were excluded. Patients underwent a comprehensive preoperative clinical, biochemical, and echocardiographic evaluation, STE was performed offline by an experienced operator blinded to clinical and basic echocardiographic data.

The primary endpoint was a composite outcome of all-cause or cardiovascular mortality and/or hospitalizations for heart failure. The secondary endpoint was postoperative functional capacity, assessed according to NYHA class at the last available follow-up visit or telephone contact.

Follow-up was conducted through scheduled on-site outpatient visits or structured telephone interviews, performed by a dedicated investigator blinded to preoperative echocardiographic measurements. All patients completed the follow up procedures. In cases of uncertain event classification, a second blinded investigator was consulted, and consensus was reached by discussion. Heart failure hospitalization was defined as an unplanned hospital admission primarily driven by worsening signs or symptoms of heart failure with objective evidence of congestion requiring initiation or intensification of intravenous diuretic therapy, according to the 2021 ESC Heart Failure Guidelines criteria [10].

The study protocol complied with the ethical guidelines of the Declaration of Helsinki and was approved by the local ethics committee.

All the study procedures followed the STROBE recommendations for observational studies.

2.1. Echocardiography

Bidimensional echocardiographic assessment was performed according to the recommendations of the American Society of Echocardiography (ASE) and the European Association of Cardiovascular Imaging (EACVI) [11], using a high-quality ultrasound system (Vivid E9; GE, Milwaukee, Wisconsin) and a 2.5 MHz transducer with the patient in the left lateral decubitus position. Ultrasound settings were manually adjusted to optimize grayscale definition of the endocardial based on patient characteristics.

Regarding preoperative echocardiographic parameters, LV diameters and thickness were measured from the parasternal long-axis view, left intracavitary volumes were measured from the apical four-chamber view. Subsequently, ejection fraction (EF) was calculated using the modified Simpson biplane method.

RV diameters, right ventricular fractional area change (RVFAC), and the ventricular sphericity index (mean diameter / longitudinal diameter) were evaluated in apical 4 chamber view.

Left and right atrial area and volume were measured using the biplane disk sum method (modified Simpson formula) in end-diastole from the apical four-chamber window.

LV and LA volumes were then indexed according to the patients' body surface area.

Maximum early diastolic (E) and late diastolic (A) velocities were assessed by trans-mitral pulsed wave Doppler to calculate E/A ratio; then, peak systolic (S'), early diastolic (e'), and late diastolic (a') annular velocities were obtained by tissue Doppler imaging (TDI), E/e' ratio was calculated and used as index of LV filling pressure.

Tricuspid annular plane systolic excursion (TAPSE) was measured using the M-mode function in the apical four-chamber view. RV dimensions and function were measured in apical four chamber view, systolic pulmonary artery pressure (sPAP) was estimated as the sum of trans-tricuspid pressure peak systolic gradient and right atrial pressure derived from the diameter and collapsibility of the inferior vena cava.

MR severity was assessed with color flow Doppler using a 4-grade scale (mild, moderate, medium, severe regurgitation). The possible presence of valve flail or leaflet prolapse was then assessed. The mitral annulus diameter was measured at end-systole from the apical two-, three-, and four-chamber views, and the annulus was considered dilated when >35 mm, as recommended by the ASE/ EACVI guidelines [11]. Using color flow Doppler, the vena contracta was measured in patients with a single regurgitant jet.

Other valvular heart diseases were quantified by bidimensional echocardiography according to ASE/EACVI recommendation [11].

2.2. Speckle tracking analysis

For STE, apical 4-, 2- and 3-chamber 2-dimensional gray-scale images with a stable electrocardiographic recording were analyzed. LA strain was calculated using apical 4- and 2-chamber views, using the QRS wave as cardiac cycle starting point; dedicated views were utilized for LV, LA and RV analysis, allowing a more reliable delineation of the atrial endocardial border. Three consecutive heart cycles were recorded and averaged. The frame rate was 60–80 frames/s. Analysis was performed off-line by a single experienced and independent echocardiographer, using a commercially available semiautomated 2-dimensional strain software (EchoPac, GE, Milwaukee, Wisconsin) with automated functional imaging (AFI) algorithms dedicated to LV and LA. LV GLS was calculated as the average of 4-chambers, 2-chambers and 3-chambers longitudinal strain curves. Global PALS was calculated at the end of the reservoir phase as an average of the values observed in all LA segments in the 4- and 2-chamber views. Free-wall RV longitudinal strain (fwRVLS) was derived by a ROI of three segments (basal, medial, &

apical) including only RV free wall.

For subsequent MW analysis, the operator confirms the event timing of aortic and mitral events by the apical three-chamber view synchronized with the ECG trace. Brachial arterial pressure was available for all patients and was measured during the physical examination immediately before performing echocardiography. Blood pressure is used by the software to fit a non-invasively estimated LV pressure curve with peak blood pressure values and valvular events.

The software automatically creates a pressure-deformation loop, derived from the estimated LV pressure curve and GLS, and generates four myocardial performance indices: global work index (GWI), which is the total work done by the left ventricle during systole, calculated from MV closure to MV opening adding isovolumetric contraction and isovolumetric relaxation, global constructive work (GCW), which is the productive work done during systole and includes both muscle shortening in systole and muscle lengthening during isovolumetric relaxation, the global wasted work (GWW), which is the non-productive work done during systole and includes the muscle lengthening in systole and the shortening work during isovolumetric relaxation, and finally, the global work efficiency (GWE), which is a ratio of constructive work divided by the sum of constructive work and wasted work (GCW/GCW + GWW).

2.3. Statistical analysis

Continuous variables were expressed as mean $\pm$ standard deviation (SD), and binary variables were expressed as counts or percentages. Continuous variables were tested for normality using the Kolmogorov-Smirnov test, and then compared using the *t*-test. Categorical variables were compared using the χ^2 test.

Receiving Operating Curves (ROC) were used to calculate the prognostic power of echocardiographic variables, including the area under curve (AUC) value, and their sensitivity and specificity using standard definitions.

The variables selected using this process were discretized using the Youden index on the respective ROC curves to find the threshold value. Internal validation was performed by bootstrap resampling (2000 replicates): optimism-corrected estimates of discrimination were computed for global PALS and fwRVLS, and the stability of the Youden-derived thresholds was assessed by re-deriving each cut-off within every bootstrap sample. These threshold values were used to divide the population into three risk groups according to a progressive damage of one or both among LA and RV, to which survival analysis using Kaplan-Meier curves was applied to determine the predictive value of the primary endpoint for each group. Postoperative NYHA class was dichotomized as $>II$ versus $\leq II$. The association of individual echocardiographic variables with this outcome was assessed by logistic regression, and effect sizes were reported as odds ratios (OR) with 95% CI. Bland Altman analysis was used to test the intra-observer and inter-observer reproducibility of strain measures over a random sample of 20 patients with calculation of intra-class-correlation (ICC) coefficients.

Statistical Package for the Social Sciences (SPSS) version n.27 was used for the analysis. A *p*-value lower than 0.05 was considered significant.

3. Results

3.1. Baseline demographic and echocardiographic data

Data from 110 subjects with a mean age of 64 ± 13 years, 59% male, who underwent cardiac surgery for severe degenerative mitral regurgitation (83 only mitral valve repair, 3 mitral + tricuspid valve repair, 8 mitral valve repair + coronary artery bypass grafting, 16 mitral valve replacement) were analyzed; the initial study cohort included 137 patients, then 20 patients was excluded due to non-sinus rhythm, 4 for previous cardiac surgery, 3 for concomitant severe aortic regurgitation.

Data regarding preoperative clinical, biohumoral and echocardiographic data in the study population are reported in Table 1. Regarding NYHA class, 25% of patients were in class I, 52% in class II, and 23% in class III.

As for echocardiographic variables, the population presented preserved LV systolic function (mean EF: $58 \pm 4\%$), a slightly increased LV mass (mean indexed LV mass: 117 ± 29 g/m²), a LA dilatation (mean indexed AS volume: 55 ± 19 ml), a mild dilation of the tricuspid annulus (mean diameter: 36 ± 4 mm) and a dilation of the mitral annulus (mean diameter 40 ± 4 mm). RV systolic function was preserved, and pulmonary artery systolic pressure were slightly preserved (mean PAPs: 32 ± 9 mmHg). As regards STE parameters, there was a reduced PALS ($22.4 \pm 8.4\%$), a reduced RVLS ($-19.0 \pm 5.4\%$), and a relatively preserved biventricular strain (LV GLS = -19.9 ± 4.2 , fwRVLS = $-22.2 \pm 7.5\%$). Regarding MW, the obtained parameters fell within the normal range.

Overall reproducibility of STE parameters was excellent for left heart (intra-observer ICC 0.95 [0.95–0.96] for LV GLS and all MW parameters, 0.93 [0.90–0.95] for global PALS, inter-observer ICC 0.95 [0.94–0.95] for LV GLS and all MW parameters, 0.93 [0.90–0.94] for global PALS) and good for RV strain (ICC = 0.87 [0.84–0.9], interobserver ICC = 0.85 [0.84–0.86]).

3.2. Follow up data

The median follow-up of patients was 17 (10–29) months, the primary endpoint occurred in 10 patients, distributed in 7 deaths (6.4%) of which 4 for cardiovascular reasons and 3 hospitalizations for heart failure (2.7%). 18 patients developed atrial fibrillation during follow up. No patient had significant residual MR during follow up, while 10 patients had tricuspid regurgitation $>$ moderate at follow up. Table 2 shows the clinical and echocardiographic characteristics of patients who developed events vs. patients without events. All strain values were reduced in patients with events, however, the only two parameters showing significant differences in patients with vs. without events were global PALS and fwRVLS. Using receiver operator curve (ROC) curves, global PALS– with optimal cut-off $\leq 21.5\%$ – and fwRVLS (cut-off $\geq -22\%$) were identified as the two best predictors for the primary endpoint, with an AUC 0.64 (95% CI 0.56–0.73) and AUC 0.63 (95% CI 0.55–0.75), respectively (Fig. 1). Internal validation by bootstrap resampling (2000 replicates) yielded optimism-corrected C-indices of 0.61 for global PALS and 0.47 for fwRVLS. Bootstrap re-derivation of the optimal thresholds produced wide distributions, indicating that the exact cut-off values are estimated with uncertainty given the limited number of events.

The study population, which had a median postoperative hospital stay of 8 (7–10) days, was then divided into 3 groups: Group 1 with both preserved LA and RV strain ($n = 32$: PALS $>21.5\%$ and fwRVLS $< -22\%$), Group 2 with either impaired LA or RV strain ($n = 46$: PALS $\leq 21.5\%$ and fwRVLS $< -22\%$ ($n = 16$) or PALS $>21.5\%$ and fwRVLS $\geq -22\%$ ($n = 28$)), Group 3 with both impaired LA and RV strain ($n = 32$: PALS $\leq 21.5\%$ and fwRVLS $\geq -22\%$). Over 10 events registered, 0 were in Group 1, 3 in Group 2 and 7 in Group 3 ($p < 0.0001$). Since the lowest-risk group (Group 1) had 0 events, we compared the two groups with the highest event rates. Patients in Group 3 had a higher event rate than Group 2 (7/10 vs 3/10), corresponding to a hazard ratio of 2.16 (95% CI 0.50–9.25, log-rank $p = 0.30$, underpowered due to the low number of events). Kaplan Meier survival curves showed a good risk stratification of the event-free survival rate with these two parameters for the primary endpoint (Fig. 2).

3.3. Incremental value of fwRVLS

The evaluation on whether fwRVLS added prognostic information beyond global PALS was performed by comparing two Cox models for the primary composite endpoint. In the univariable model, PALS was associated with the outcome (HR 0.91 per 1% increase, 95% CI

Table 1

General, clinical and echocardiographic characteristics of the study population divided into the 3 groups.

Variables	Overall	Group 1 (PALS > 21.5% and fwRVLS < -22%) (n = 32)	Group 2 (PALS ≤ 21.5% or fwRVLS ≥ -22%) (n = 46)	Group 3 (PALS ≤ 21.5% and fwRVLS ≥ -22%) (n = 32)	p-value
Age (y)	64 ± 13	58 ± 15	65 ± 13	70 ± 10	0.001
Sex, m (n, %)	64 (59%)	23 (62.5%)	29 (66%)	12 (39%)	0.008
BMI (kg/m ²)	25 ± 4	24 ± 3	25 ± 3	27 ± 5	0.084
BSA (m ²)	1.8 ± 0.2	1.86 ± 0.19	1.8 ± 0.2	1.8 ± 0.3	0.76
sBP (mmHg)	129 ± 17	132 ± 18	129 ± 15	127 ± 20	0.56
HR (bpm)	75 ± 15	75 ± 12	75 ± 15	76 ± 17	0.50
Hemoglobin (g/dl)	13.9 ± 1.6	14 ± 1.7	13.9 ± 1.6	13.5 ± 1.5	0.19
Creatinine (mg/dl)	1.0 ± 0.3	0.94 ± 0.34	1.04 ± 0.29	1.03 ± 0.31	0.26
Na ⁺ (mEq/L)	141 ± 2	141 ± 1.3	141 ± 2	141 ± 3	0.99
K ⁺ (mEq/L)	4.3 ± 0.4	4.3 ± 0.4	4.3 ± 0.4	4.2 ± 0.4	0.99
Diabetes	7 (7%)	1 (3%)	2 (5%)	4 (13%)	0.55
Smoker	6 (6%)	2 (6%)	3 (7%)	2 (7%)	0.93
Ex-smoker (<1 year) (n, %)	22 (21%)	6 (19%)	9 (21%)	6 (19%)	0.99
Arterial hypertension (n, %)	57 (53%)	12 (37%)	22 (51%)	22 (71%)	0.02
Dislipidemia (n, %)	33 (31%)	7 (22%)	14 (33%)	12 (39%)	0.29
AF (n, %)					
Paroxysmal	14 (13%)	2 (3%)	6 (14%)	6 (19%)	0.02
Permanent ^a	7 (7%)	1 (3%)	1 (2%)	5 (16%)	0.22
Prior HF (n, %)	19 (18%)	4 (12%)	6 (14%)	9 (29%)	0.33
ACEi/ARBs(n, %)	49 (45%)	10 (31%)	18 (39%)	20 (63%)	0.04
β blockers (n, %)	48 (45%)	15 (47%)	18 (42%)	14 (45%)	0.52
Ca ²⁺ antagonists (n, %)	21 (20%)	3 (9%)	11 (26%)	8 (26%)	0.17
Diuretics (n, %)	36 (34%)	6 (18%)	13 (30%)	14 (45%)	0.09
MRA (n, %)	12 (11%)	3 (9%)	5 (12%)	4 (13%)	0.88
NYHA class (n, %)					
1	25 (24%)	9 (28%)	11 (26%)	5 (16%)	
2	55 (52.9%) 24	19 (59%)	21 (50.0%)	15 (50.0%)	0.37
3	(23.1%)	4 (12%)	10 (23.8%)	10 (33.3%)	
LV EF (%)	58 ± 4	59 ± 4	59 ± 3	57 ± 5	0.20
EDD index (mm/m ²)	28 ± 4	28 ± 3.6	28.18 ± 3.68	28.43 ± 4.00	0.88
ESD index (mm/m ²)	18 ± 4	17 ± 3	17.34 ± 3.74	18.45 ± 3.12	0.39
LAVi (ml/m ²)	55 ± 19	50 ± 13	50 ± 15	60 ± 22	0.12
EDD RV mean (mm)	30 ± 4	29 ± 3	30 ± 4	31 ± 4	0.03
E/A	1.32 ± 0.49	1.4 ± 0.5	1.39 ± 0.46	1.13 ± 0.47	0.07
E/E'm	10.34 ± 3.72	10 ± 3.7	10.27 ± 3.74	10.97 ± 3.98	0.68
S' (m/s)	0.15 ± 0.03	0.16 ± 0.04	0.15 ± 0.03	0.13 ± 0.03	0.005
TAPSE (mm)	23 ± 4	24 ± 3	24 ± 3	21 ± 4	0.007
RVFAC (%)	47 ± 8	50 ± 9	48 ± 8	45 ± 9	0.38
sPAP (mmHg)	32 ± 9	30 ± 8	32 ± 9	37 ± 11	0.02
Annulus in 4chambers view (mm)	40 ± 4	40 ± 4	39 ± 4	40 ± 5	0.52
Tricuspid annulus (mm)	36 ± 4	36 ± 3	36 ± 4	36 ± 4	0.84
Tricuspid regurgitation (n, %)					
1+	43 (39%)	3 (9%)	16 (36%)	8 (26%)	
2+	45 (41%)	15 (47%)	18 (41%)	16 (52%)	0.40
3+	13 (12%)	13 (41%)	4 (9%)	6 (19%)	
4+	1 (0.9%)	1 (3%)	1 (2%)	0 (0%)	
Aortic stenosis (n, %)	1 (1%)	0 (0%)	0 (0.0%)	1 (3%)	0.31
Aortic regurgitation (n, %).					
1+ 2+	35 (32%)	21(66%)	23 (52%)	19 (61%)	
3+	13 (12%)	9(28%)	13 (29%)	9 (29%)	0.23
Mitral stenosis (n, %)	1 (0.9%)	2(6%)	8 (19%)	3 (10%)	
EROA (cm ²)	0.69 ± 0.12	0 (0%)	1 (2%)	0 (0%)	0.46
Regurgitant volume (ml)	83 ± 26	0.68 ± 0.1	0.69 ± 0.12	0.7 ± 0.11	0.09
Vena contracta (mm)	82 ± 26	82 ± 26	82 ± 30	83 ± 21	0.12
Mitral annulus dilatation	0.8 (0.7-1.2)	0.7 (0.6-1.2)	0.8 (0.7-1.1)	0.8 (0.6-1.2)	0.05
Flail	59 (54%)	22 (68%)	31 (70%)	28 (87%)	0.003
	31 (28%)	7 (21.9%)	15 (34%)	9 (28%)	
Posterior leaflet	25(79%)	5 (72%)	12 (80%)	7 (78%)	
Anterior leaflet	4 (13%)	1 (14%)	2 (13%)	1 (11%)	0.19
Bileaflet	2 (8%)	1 (14%)	1 (7%)	1 (11%)	
Mitral valve prolapse	79 (71%)	26 (81%)	34 (77%)	19 (59%)	
Anterior leaflet	42 (53%)	13 (50%)	18 (53%)	11 (58%)	0.21
Posterior leaflet	15 (19%)	7 (27%)	7 (21%)	3 (16%)	
Bileaflet	22 (28%)	6 (23%)	9 (26%)	5 (26%)	
Global PALS (%)	22.4 ± 8.4	28 ± 6.6	24.3 ± 7.2	14.9 ± 4.8	<0.001
GLS (%)	-19.9 ± 4.2	-21.92 ± 3.94	-20.8 ± 2.8	-17.0 ± 4.7	0.01
Free wall RVLS (%)	-22.2 ± 7.5	-29.71 ± 5.48	-21.8 ± 6.4	-16.0 ± 3.9	<0.001
GWV (mmHg%)	1927 ± 573	2232.48 ± 587.50	1986 ± 466	1593 ± 574	<0.001

(continued on next page)

Table 1 (continued)

Variables	Overall	Group 1 (PALS > 21.5% and fwRVLS < -22%) (n = 32)	Group 2 (PALS ≤ 21.5% or fwRVLS ≥ -22%) (n = 46)	Group 3 (PALS ≤ 21.5% and fwRVLS ≥ -22%) (n = 32)	p-value
GCW (mmHg%)	2518 ± 634	2839.96 ± 626.08	2563 ± 499	2188 ± 697	0.002
GWW (mmHg%)	243 ± 156	208.74 ± 98.37	234 ± 159	271 ± 188	0.25
GWE (mmHg%)	90 ± 6	91.59 ± 4.41	90 ± 6	88 ± 5	0.05

ACE, angiotensin converting enzyme; AF, atrial fibrillation; ARB, angiotensin receptor blocker; BMI, body mass index; BSA, body surface area; E/A, early / late diastolic wave by pulsed-wave Doppler; E/E', early diastolic wave by pulsed wave Doppler / early diastolic mitral annular velocity by tissue Doppler imaging; EDD, end diastolic diameter; EF, ejection fraction; EROA, effective regurgitant orifice area; ESD, end systolic diameter; GCW, global constructive work; GWE, global work efficiency; GWI, global work index; GWW, global wasted work; HF, heart failure; HR, heart rate; LV, left ventricle; MRA, mineralcorticoid receptor antagonist; NYHA, New York Heart Association; PALS, peak atrial longitudinal strain; RV, right ventricle; RVFAC, right ventricular fractional area change; RVLS, right ventricular longitudinal strain; s', systolic annular velocity by tissue Doppler imaging; sBP, systolic blood pressure; sPAP, systolic pulmonary artery pressure; TAPSE, tricuspid annular plane systolic excursion.

^a Permanent AF was meant as history of joint decision by the patient and the physician to stop rate control, although included patients presented with sinus rhythm at the time of the echocardiographic exam.

0.84–1.00, $p = 0.041$), whereas fwRVLS was not (HR 0.97 per 1% increase, 95% CI 0.88–1.08, $p = 0.60$). Adding fwRVLS to PALS did not significantly improve model fit (likelihood ratio test $\chi^2 = 0.33$, $p = 0.57$), and fwRVLS was not independently associated with the primary endpoint after adjustment for PALS (HR 1.03, 95% CI 0.92–1.15, $p = 0.56$). PALS and fwRVLS were only modestly correlated ($r = 0.28$, $p = 0.004$). Given the limited number of primary events, these estimates should be regarded as exploratory.

Table 1 shows the clinical and echocardiographic characteristics of the two groups with the highest risk of events (Group 2 vs. Group 3). Among general characteristics there was no significant differences between the two groups. Patients in group 3 were mainly female ($p = 0.008$) and were mainly treated with ACE inhibitors or ARBs ($p = 0.04$). As regards MR etiology, patients in Group 3 had a higher percentage of mitral annulus dilation (87% vs. 70% and 68%, $p = 0.09$).

Among echocardiographic parameters, LV EF was on average preserved in both groups (p -value = 0.2). Group 3 showed lower but preserved longitudinal RV function (TAPSE 21 ± 4 mm vs 24 ± 3 mm and 25 ± 3 mm, p -value = 0.006; TDI s' 0.13 ± 0.03 m/s vs. 0.15 ± 0.03 m/s and 0.16 ± 0.04 m/s, p -value = 0.007); RVFAC did not differ significantly between the groups (p -value = 0.38) and was preserved. A slightly increased PAPs was observed in group 3 (p -value = 0.02).

Regarding STE parameters, GLS was significantly lower in group 3 ($-17 \pm 5\%$ vs. $-20.8 \pm 2.8\%$ and $-21.9 \pm 3.9\%$ p -value ≤ 0.001), accordingly was global PALS ($14.9 \pm 4.8\%$ vs. $24.3 \pm 7.2\%$ p -value ≤ 0.001), and fwRVLS ($-16 \pm 3.9\%$ vs. $-21.8 \pm 6.4\%$ and -29.7 ± 5.5 , p -value ≤ 0.001).

Regarding MW, there were two parameters considerably lower in group 3: GWI (1593 ± 574 mmHg vs. 1986 ± 466 mmHg and 2232 ± 587 mmHg, p -value < 0.001) and for GCW (2188 ± 697 mmHg vs. 2563 ± 499 mmHg and 2840 ± 466 , p -value = 0.002).

Regarding capacity, GWW was the only MW parameter that predicted NYHA class >II at the last available follow-up, with an OR of 1.35 (95% CI 1.01–1.82; $p = 0.04$) per 100 mmHg% increase, i.e., each 100 mmHg% increase in GWW was associated with an approximately 35% higher odds of persistent NYHA class >II.

4. Discussion

Our study was the first to evaluate the prognostic impact of progressive LA and RV dysfunction in MR as a predictor of worse clinical outcome in patients undergoing cardiac surgery using STE parameters. Although the number of events was limited, our findings may raise some suggestion for clinical practice. Particularly, all patients who had both preserved LA and RV strain had no event, while an increasing risk of death or HF hospitalization was found according to the impairment of only LA/RV or both these cardiac chambers, suggesting that the use of speckle tracking may aid the identification of subclinical cardiac damage in patients with MR to guide the referral for cardiac surgery. Furthermore, myocardial work with GWW emerged as a potential

predictor of postoperative functional capacity.

Given the small number of events, the proposed PALS and fwRVLS thresholds should be regarded as exploratory. The prognostic signal resides primarily in the continuous parameters, and the dichotomization is retained only as a clinically oriented illustration of graded risk. An impaired LA reservoir function in a comparable range has previously been associated with adverse outcome in patients with severe MR undergoing surgery [6], supporting the biological plausibility of global PALS, although the precise numerical threshold is cohort-dependent. These thresholds warrant external validation in larger multicenter cohorts before clinical application.

The prognostic role of global PALS in MR has already been studied: in a cohort of patients with asymptomatic severe MR and preserved EF, lower LA strain predicted subsequent death or the need for mitral valve surgery [12]. Furthermore, Candan et al. [13] demonstrated that global PALS, combined with LA volume indexed, had high accuracy in identifying LA fibrosis and fibrillation in patients undergoing surgery for severe MR. Debonnaire et al. [14] demonstrated that LA strain is strongly correlated with the presence of conventional indications for mitral valve surgery and, even more importantly, is associated with long-term postoperative survival. Additionally, in a previous study [6], we found a good prognostic estimation of a combined endpoint of hospitalization for heart failure and cardiovascular/all-cause mortality for global PALS $\leq 21\%$, similar to this study, and that global PALS was associated with functional capacity after surgery, suggesting its potential value to assess clinical and functional outcomes in patients referred for mitral surgery. Accordingly, in a recent study, among speckle tracking parameters including MW, we showed that global PALS was the most reliable to predict NYHA class in patients with different grades of MR [9].

The present study demonstrated that, despite the discriminatory power of the single strain parameter was modest, a combination of global PALS and fwRVLS provides a more precise risk stratification in patients undergoing mitral valve surgery, since the role of a subclinical RV dysfunction (most represented in Group 2 and Group 3) may be crucial for postoperative outcome in these patients, with a significant higher risk in patients with dysfunction of both chambers [15,16].

Although fwRVLS did not provide incremental value over PALS as a predictor of the primary endpoint, RV involvement contributed to risk assessment within our multiparametric three group stratification. This suggests that RV function is best interpreted as part of a combined phenotypic characterization of advanced MR, rather than as a stand-alone prognostic marker.

The preoperative echocardiographic assessment of RV function in patients undergoing cardiac surgery is a topic of increasing interest, since existing literature mainly focuses on the study of postoperative RV function [17].

RV strain has been identified as a reliable prognostic predictor in cardiac surgery, however, its specific prognostic application mitral valve surgery for primary MR remains under investigation [18,19]. Sabe et al. [20] analyzed a cohort of patients with ischemic cardiomyopathy and

Table 2

General, clinical and echocardiographic characteristics of patients who reached the combined endpoint or not.

Variables	Events (n = 10)	No events (n = 100)	p-value
Age (years)	65 ± 9	64 ± 13	0.34
BMI (kg/m ²)	23 ± 7	25 ± 4	0.15
BSA (m ²)	1.7 ± 0.2	1.8 ± 0.2	0.09
sBP (mmHg)	135 ± 15	129 ± 17	0.22
HR (bpm)	74 ± 11	74 ± 16	0.88
Hemoglobin (g/dl)	12.8 ± 1.8	12.9 ± 1.5	0.37
Creatinine (mg/dl)	0.98 ± 0.39	1 ± 0.28	0.84
Na ⁺ (mEq/L)	140 ± 2	141 ± 2	0.05
K ⁺ (mEq/L)	4.4 ± 0.4	4.2 ± 0.4	0.31
Diabetes (n, %)	2 (20)	5 (5)	0.08
Smoker (n, %)	1 (10)	4 (4)	0.5
Ex-smoker (<1 year) (n, %)	1 (10)	20 (20)	0.5
Arterial hypertension (n, %)	8 (80)	44 (44)	0.05
Dislipidemia (n, %)	2 (20)	28 (28)	0.48
AF (n, %)	4 (40)	10 (10)	0.03
Paroxysmal 14 (13%)	–	6 (6)	
Permanent ^a 7(7%)	–	–	
Prior HF (n, %)	2 (20)	15 (15)	0.77
ACEi/ARBs(n, %)	7 (70)	37 (37)	0.2
β blockers (n, %)	3 (30)	42 (42)	0.33
Ca ²⁺ antagonists (n, %)	3 (30)	15 (15)	0.28
Diuretics (n, %)	–	–	0.99
MRA (n, %)	1 (10)	9 (9)	
NYHA class	–	–	
1	3 (30)	23 (23)	0.24
2	3 (30)	50 (55)	
3	4 (40)	18 (20)	
LVEF (%)	56 ± 3	58 ± 5	0.19
LV EDV index (mm/m ²)	29 ± 2	28 ± 4	0.84
LV ESV index (mm/m ²)	29 ± 2	28 ± 4	0.49
LAVI (ml/m ²)	64 ± 24	54 ± 19	0.18
Medium RV diameter (mm)	29 ± 4	30 ± 4	0.48
E/A	1.2 ± 0.38	1.33 ± 0.48	0.54
E/E'm	11 ± 5	10 ± 3.5	0.61
Tricuspid s' (m/s)	0.15 ± 0.03	0.15 ± 0.03	0.77
TAPSE (mm)	22 ± 3.6	23 ± 4	0.15
RVFAC (%)	49 ± 8	47 ± 7	0.41
sPAP (mmHg)	32 ± 5	32 ± 3	0.85
Annulus in 4ch (mm)	41 ± 3	40 ± 3	0.43
Tricuspid annulus (mm)	37 ± 5	36 ± 4	0.71
Tricuspid regurgitation (n, %)	–	–	0.54
1+	2 (22)	37 (37)	
2+	5(56)	37 (37)	
3+	2 (22)	9 (9)	
4+	–	1 (1)	
Aortic stenosis (n, %)	–	1 (1)	0.74
Aortic regurgitation (n, %).	–	–	0.35
1+	2 (22)	27 (27)	
2+	–	13 (13)	
3+	–	–	0.002
Mitral stenosis (n, %)	1 (10)	–	
Mitral annulus dilatation	7 (70)	76 (76)	0.29
Flail	–	31 (31)	0.027
Mitral valve prolapse	5 (50)	74 (74)	0.09
Global PALS (%)	19 ± 10	24 ± 9	0.03
GLS (%)	−18.9 ± 5.2	−20.2 ± 4.1	0.14
fwRVLS (%)	−19.9 ± 7.2	−22.3 ± 7.3	0.02
GWV (mmHg%)	1782 ± 610	1959 ± 582	0.24
GCW (mmHg%)	2329 ± 544	2551 ± 661	0.31
GWV (mmHg%)	255 ± 133	241 ± 161	0.79
GWE (mmHg%)	89 ± 5	89 ± 6	0.73

ACE, angiotensin converting enzyme; AF, atrial fibrillation; ARB, angiotensin receptor blocker; BMI, body mass index; BSA, body surface area; E/A, early / late diastolic wave by pulsed-wave Doppler; E/E', early diastolic wave by pulsed wave Doppler / early diastolic mitral annular velocity by tissue Doppler imaging; EDD, end diastolic diameter; EF, ejection fraction; ESD, end systolic diameter; GCW, global constructive work; GWE, global work efficiency; GWV, global work index; GWV, global wasted work; HF, heart failure; HR, heart rate; LV, left ventricle; MRA, mineralocorticoid receptor antagonist; NYHA, New York Heart Association; PALS, peak atrial longitudinal strain; RV, right ventricle; RVFAC, right ventricular fractional area change; RVLS, right ventricular longitudinal strain; s', systolic annular velocity by tissue Doppler imaging; sBP, systolic blood

pressure; sPAP, systolic pulmonary artery pressure; TAPSE, tricuspid annular plane systolic excursion.

^a Permanent AF was meant as history of joint decision by the patient and the physician to stop rate control, although included patients presented with sinus rhythm at the time of the echocardiographic exam.

demonstrated that MR severity is an independent predictor of RVFAC in patients with ischemic MR, and in the same study, for every 10% decrease in RVFAC, there was a 17% increased risk of mortality ($p = 0.008$). Meanwhile, Chrustowicz et al. [21] analyzed a cohort of patients with severe primary MR using standard echocardiographic parameters and demonstrated that a preoperative reduction in TAPSE and tricuspid annulus s' had a sensitivity of 90% and a specificity of 63% in predicting a 10% postoperative reduction in LVEF. The same study group also demonstrated an independent correlation between preoperative RV dilation and mortality or the need for heart transplantation after mitral valve repair [22].

While the evidence regarding the use of RV strain in the preoperative evaluation of patients undergoing mitral valve surgery is scarce, its prognostic role has been widely established in heart failure [23]. Particularly, it has showed to be a reliable prognostic marker in advanced heart failure, with a crucial clinical application in the selection of patients for advanced therapeutic strategies [24,25]. In fact, it is now recommended an essential parameter for patients referral to LV assist device implantation, as reduced RV free wall deformation before of the implant identifies patients at increased risk of developing RV failure in the early or late postoperative period [26,27].

Overall, RV strain may represent a rapid and useful noninvasive tool for the preoperative assessment of patients with severe MR referred for cardiac surgery.

Moreover, in our population GWW was the only STE parameter associated with NYHA class after surgery: each 100 mmHg% increase in GWW was associated with an approximately 35% higher odds of persistent NYHA class >II. This effect size is clinically relevant when considering that the reference GWW values reported by Manganaro et al. [28] are 85 (49–129) mmHg% for men and 90 (48–145) mmHg% for women, so that clinically meaningful deviations in GWW occur on the scale of tens to hundreds of mmHg%. The correlation of this parameter with worse functional capacity could be explained by the fact that, since GWW is defined as the ineffective contribution to LV ejection or relaxation, this dissipation of contractile energy may be increased, indicating reduced cardiac performance that persists postoperatively, resulting in these patients' NYHA class exceeding II without the expected benefit of surgical therapy. To date, no study has studied the association between MW and postoperative functional capacity in a similar cohort of patients, however, some author assessed the prognostic power of MW in patients with MR are; Yedidya et al. [29] found a worse prognosis in patients with secondary MR without surgical therapy who had a GWI ≤ 500 mmHg% and GCW ≤ 750 mmHg%, i.e. values indicating considerably reduced LV function. Conversely, in the same study, a GWW < 300 mmHg% was associated with higher mortality compared to patients with a higher value. Further studies are certainly needed to further investigate the role of MW in the prognostic stratification of MR patients and to understand the modification of some of its parameters in the pre- and post-operative phase.

All this given, our results suggest a potential role of STE in the pre-operative evaluation of patients with primary MR, since, thanks to its higher sensitivity and feasibility, it may add useful information to guide therapeutic decisions on whether to anticipate surgery (in low-to-intermediate risk groups) due to the detection of subclinical damage or to search other therapeutic strategies due to high risk of poor post-operative outcome (in high-risk group). Moreover, our analysis strengthens the evidence regarding RV as a pivotal element for prognostic assessment in these patients [30], suggesting a comprehensive assessment including multichambered evaluation also in preoperative period.

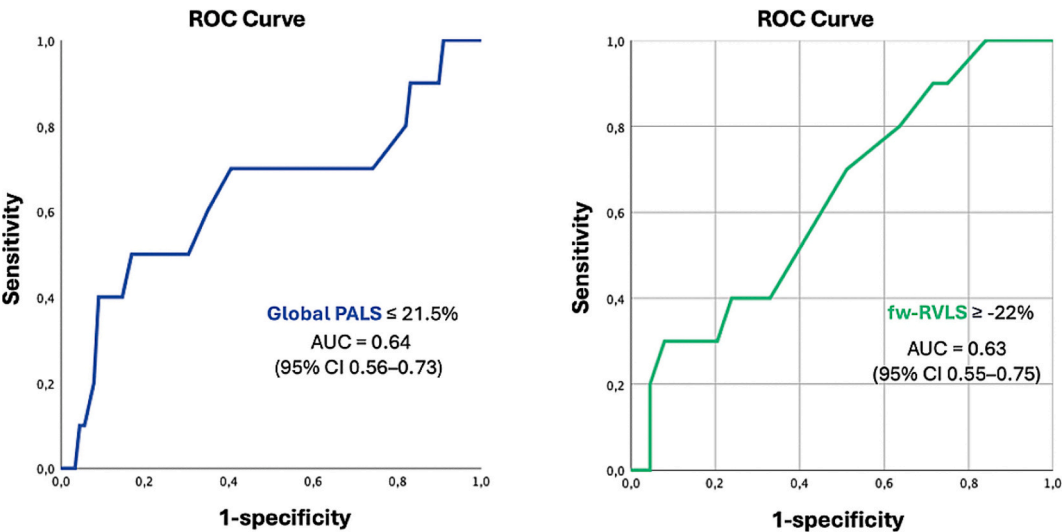


Fig. 1. ROC curves for PALS $\leq 21.5\%$ as a predictor of primary endpoint (AUC = 0.64) and for fwRVLS $\geq -22\%$ as predictor of primary endpoint (AUC = 0.63).

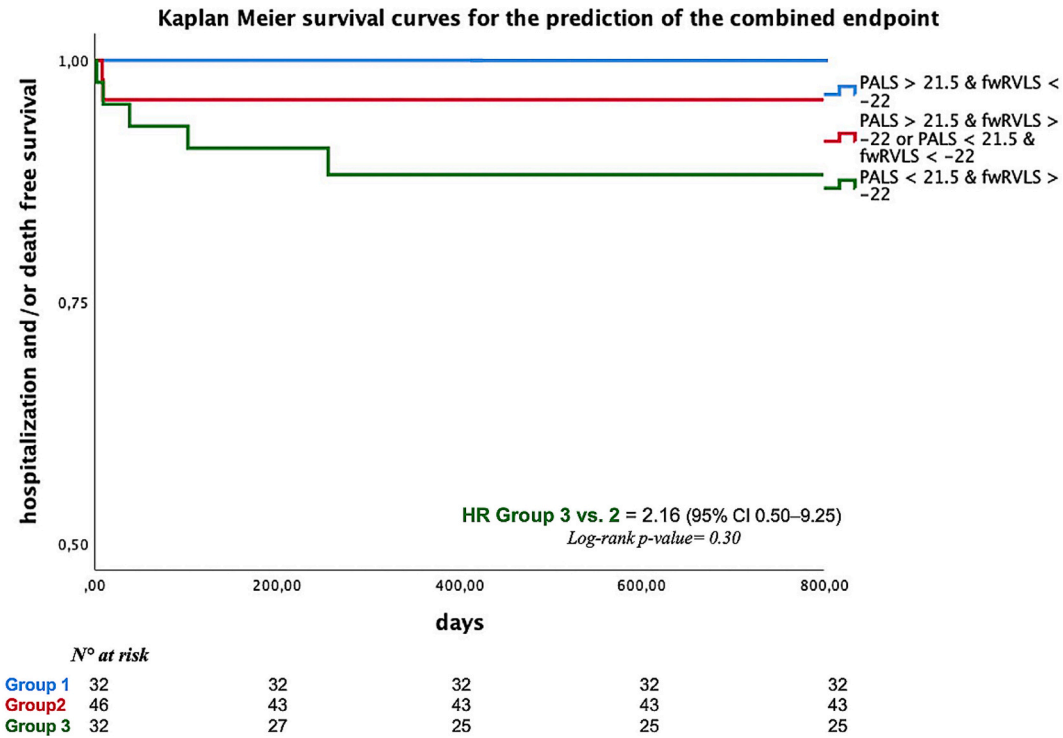


Fig. 2. Kaplan–Meier curves for the prediction of primary endpoint-free survival of the population divided into the three risk groups.

4.1. Limitations

Despite the promising results of this study, there are some limitations that should be acknowledged: first of all, the limited sample size of the population with few events and relatively short follow up, which requires to confirm these findings over a longer follow up and a larger population to carry out the prognostic endpoint. Then, intrinsic limitations of STE measures such as vendor dependency and load dependency should be considered. Moreover, sometimes RV strain measurement may be challenging due to poor acoustic window and incomplete visualization of RV free wall. Finally, the MW technique represents a still emerging technique, which still requires standardization in different clinical settings. Detailed intraoperative data (cardiopulmonary bypass and aortic cross-clamp times) and systematic postoperative RV

reassessment were not collected in this preoperatively focused study. Moreover, the limited number of events precluded a meaningful analysis of procedure-specific subgroups or formal adjustment for surgical type. Larger cohorts will be needed to assess the prognostic impact of surgical heterogeneity.

5. Conclusion

MR is the most common indication for cardiac surgery, which is still characterized by poor long-term prognosis in some patients. Therefore, the preoperative risk stratification of these patients is fundamental to aid decision-making on the selection of therapeutic strategies in these patients. STE may represent a rapid, noninvasive and useful tool to identify subtle cardiac damage and aid prognostic stratification. The combined

assessment of global PALS and fwRVLS may provide additional information to delineate increasing risk of poor clinical outcome following mitral valve surgery based on the dysfunction of one of these chambers or both. Also, MW may offer new predictors of functional capacity after intervention. Therefore, an integrated preoperative echocardiographic evaluation including STE and MW may be particularly useful in patients with severe MR and should be explored in bigger cohorts and longer follow-up.

CRedit authorship contribution statement

Maria Concetta Pastore: Visualization, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization, Writing – review & editing, Writing – original draft. **Federica Marrese:** Methodology, Investigation, Formal analysis, Data curation, Writing – original draft. **Andrea Marchese:** Formal analysis, Data curation, Writing – review & editing. **Lorenzo Tanzi:** Formal analysis, Data curation, Writing – review & editing. **Andrea Stefanini:** Formal analysis, Data curation, Writing – review & editing. **Antonio Capolongo:** Formal analysis, Writing – review & editing, Writing – original draft. **Veronica Lorenz:** Investigation, Data curation, Writing – review & editing. **Giuseppe Alba:** Investigation, Data curation, Writing – review & editing. **Flavio D'Ascenzi:** Investigation, Data curation, Writing – review & editing. **Marta Focardi:** Supervision, Investigation, Writing – review & editing. **Serafina Valente:** Supervision, Writing – review & editing. **Ottavio Alfieri:** Visualization, Validation, Supervision, Writing – review & editing. **Matteo Cameli:** Visualization, Validation, Supervision, Investigation, Conceptualization, Writing – review & editing. **Flavio D'Ascenzi:** Writing – review & editing. **Luna Cavigli:** Writing – review & editing. **Gianfranco Montesi:** Writing – review & editing. **Giulia Elena Mandoli:** Writing – review & editing. **Ilenia Pennisi:** Writing – review & editing. **Martina Rizzo:** Writing – review & editing.

Funding

None.

Declaration of competing interest

None.

Acknowledgements

None.

References

- [1] J.S. Gammie, S. Sheng, B.P. Griffith, E.D. Peterson, J.S. Rankin, S.M. O'Brien, J. M. Brown, Trends in mitral valve surgery in the United States: results from the Society of Thoracic Surgeons Adult Cardiac Surgery Database, *Ann. Thorac. Surg.* 87 (5) (2009) 1431–1437, discussion 1437–9, <https://doi.org/10.1016/j.athoracsur.2009.01.064>.
- [2] M.C. Pastore, G.E. Mandoli, A. Dokollari, G. Bisleri, F. D'Ascenzi, C. Santoro, M. H. Miglioranza, M. Focardi, L. Cavigli, G. Patti, S. Valente, S. Mondillo, M. Cameli, Speckle tracking echocardiography in primary mitral regurgitation: should we reconsider the time for intervention? *Heart Fail. Rev.* 27 (4) (2022 Jul) 1247–1260, <https://doi.org/10.1007/s10741-021-10100-1> (Epub 2021 Apr 7. PMID: 33829389; PMCID: PMC9197800).
- [3] F. Praz, M.A. Borger, J. Lanz, M. Marin-Cuartas, A. Abreu, M. Adamo, N. Ajmone Marsan, F. Barili, N. Bonaros, B. Cosyns, R. De Paulis, H. Gamra, M. Jahangiri, A. Jeppsson, R.J.M. Klautz, B. Mores, E. Pérez-David, J. Pöss, B.D. Prendergast, B. Rocca, X. Rossello, M. Suzuki, H. Thiele, C.M. Tribouilloy, W. Wojakowski, ESC/EACTS Scientific Document Group, ESC/EACTS guidelines for the management of valvular heart disease, *Eur. Heart J.* (2025), <https://doi.org/10.1093/eurheartj/ehaf194>, 2025 Aug 29:ehaf194.
- [4] O.A. Smiseth, O. Rider, M. Cvijic, L. Valković, E.W. Remme, J.U. Voigt, Myocardial strain imaging: theory, current practice, and the future, *JACC Cardiovasc. Imaging* 18 (3) (2025) 340–381, <https://doi.org/10.1016/j.jcmg.2024.07.011>.
- [5] L.T. Yang, J.Y. Shih, Y.W. Liu, Y.H. Li, L.M. Tsai, C.Y. Luo, W.C. Tsai, Effects of left atrial strain on functional capacity in chronic severe mitral regurgitation, *Int. J. Cardiol.* 168 (6) (2013) e151–e153, <https://doi.org/10.1016/j.ijcard.2013.08.070>.
- [6] G.E. Mandoli, M.C. Pastore, G. Benfari, G. Bisleri, M. Maccherini, G. Lisi, P. Cameli, M. Lisi, A. Dokollari, C. Carrucola, M. Vigna, G. Montesi, S. Valente, S. Mondillo, M. Cameli, Left atrial strain as a pre-operative prognostic marker for patients with severe mitral regurgitation, *Int. J. Cardiol.* 324 (2021) 139–145, <https://doi.org/10.1016/j.ijcard.2020.09.009>.
- [7] L. Ring, Y. Abu-Omar, N. Kaye, B.S. Rana, W. Watson, D.P. Dutka, V.S. Vassiliou, Left atrial function is associated with earlier need for cardiac surgery in moderate to severe mitral regurgitation: usefulness in targeting for early surgery, *J. Am. Soc. Echocardiogr.* 31 (9) (2018) 983–991, <https://doi.org/10.1016/j.echo.2018.03.011>.
- [8] O. Candan, N. Ozdemir, S.M. Aung, S. Hatipoglu, C.Y. Karabay, A. Guler, C. Gecmen, C. Dogan, O. Omaygenc, R.B. Bakal, Atrial longitudinal strain parameters predict left atrial reverse remodeling after mitral valve surgery: a speckle tracking echocardiography study, *Int. J. Cardiovasc. Imaging* 30 (6) (2014) 1049–1056, <https://doi.org/10.1007/s10554-014-0433-9>.
- [9] M.C. Pastore, F. Vannuccini, G.E. Mandoli, M. Lisi, M.A. Iuliano, A. Santoro, F. P. Niglio, E.E. Diviggiano, V. Lorenz, G. Montesi, L. Cavigli, M. Focardi, F. D'Ascenzi, M. Cameli, Myocardial work and left heart deformation parameters across primary mitral regurgitation severity, *Int. J. Cardiol.* 399 (2024 Mar 15) 131772, <https://doi.org/10.1016/j.ijcard.2024.131772>.
- [10] Authors/Task Force Members, T.A. McDonagh, M. Metra, M. Adamo, R.S. Gardner, A. Baumach, M. Böhm, H. Burri, J. Butler, J. Celutkienė, O. Chioncel, J.G. Cleland, A.J.S. Coats, M.G. Crespo-Leiro, D. Farmakis, M. Gilard, S. Heymans, A. W. Hoes, T. Jaarsma, E.A. Jankowska, M. Lainscak, C.S.P. Lam, A.R. Lyon, J.J. V. McMurray, A. Mebazaa, R. Mindham, C. Muneretto, M. Francesco Piepoli, S. Price, G.M.C. Rosano, F. Ruschitzka, A. Kathrine Skibelund, ESC Scientific Document Group, ESC Guidelines for the diagnosis and treatment of acute and chronic heart failure: developed by the Task Force for the diagnosis and treatment of acute and chronic heart failure of the European Society of Cardiology (ESC). With the special contribution of the Heart Failure Association (HFA) of the ESC, *Eur. J. Heart Fail.* 24 (1) (2021) 4–131, <https://doi.org/10.1002/ehfj.2333>, 2022 Jan.
- [11] R.M. Lang, L.P. Badano, V. Mor-Avi, J. Afilalo, A. Armstrong, L. Ernande, F. A. Flachskampf, E. Foster, S.A. Goldstein, T. Kuznetsova, P. Lancellotti, D. Muraru, M.H. Picard, E.R. Rietzschel, L. Rudski, K.T. Spencer, W. Tsang, J.U. Voigt, Recommendations for cardiac chamber quantification by echocardiography in adults: an update from the American Society of Echocardiography and the European Association of Cardiovascular Imaging, *J. Am. Soc. Echocardiogr.* 28 (1) (2015) 1–39.e14, <https://doi.org/10.1016/j.echo.2014.10.003>.
- [12] L.T. Yang, Y.W. Liu, J.Y. Shih, Y.H. Li, L.M. Tsai, C.Y. Luo, W.C. Tsai, Predictive value of left atrial deformation on prognosis in severe primary mitral regurgitation, *J. Am. Soc. Echocardiogr.* 28 (11) (2015) 1309–1317.e4, <https://doi.org/10.1016/j.echo.2015.07.004>.
- [13] O. Candan, N. Ozdemir, S.M. Aung, C. Dogan, C.Y. Karabay, C. Gecmen, O. Omaygenc, A. Güler, Left atrial longitudinal strain parameters predict postoperative persistent atrial fibrillation following mitral valve surgery: a speckle tracking echocardiography study, *Echocardiography* 30 (9) (2013) 1061–1068, <https://doi.org/10.1111/echo.12222>.
- [14] P. Debonnaire, D.P. Leong, T.G. Witkowski, I. Al Amri, E. Joyce, S. Katsanos, M. J. Schalij, J.J. Bax, V. Delgado, N.A. Marsan, Left atrial function by two-dimensional speckle-tracking echocardiography in patients with severe organic mitral regurgitation: association with guidelines-based surgical indication and postoperative (long-term) survival, *J. Am. Soc. Echocardiogr.* 26 (9) (2013) 1053–1062, <https://doi.org/10.1016/j.echo.2013.05.019>.
- [15] M. De Bonis, E. Lapenna, A. Pozzoli, T. Nisi, A. Giacomini, M. Calabrese, G. La Canna, F. Pappalardo, A. Miceli, M. Glauber, F. Barili, O. Alfieri, Mitral valve repair without repair of moderate tricuspid regurgitation, *Ann. Thorac. Surg.* 100 (6) (2015 Dec) 2206–2212, <https://doi.org/10.1016/j.athoracsur.2015.05.108>.
- [16] Y. Bobbot, B. Essayagh, G. Benfari, J.J. Bax, T. Le Tourneau, Y. Topilsky, C. Antoine, D. Rusinaru, F. Grigioni, N. Ajmone Marsan, A. van Wijngaarden, A. Hochstadt, J.C. Roussel, M. Diouf, P. Thapa, H.I. Michelena, M. Enriquez-Sarano, C. Tribouilloy, Prognostic implications of right ventricular dysfunction in severe degenerative mitral regurgitation, *J. Am. Heart Assoc.* 14 (1) (2025 Jan 7) e036206, <https://doi.org/10.1161/JAHA.124.036206>.
- [17] G.E. Mandoli, M. Cameli, G. Novo, E. Agricola, F.M. Righini, C. Santoro, F. D'Ascenzi, F. Ancona, R. Sorrentino, A. D'Andrea, M. Galderisi, S. Mondillo, Working Group of Echocardiography of the Italian Society of Cardiology, Right ventricular function after cardiac surgery: the diagnostic and prognostic role of echocardiography, *Heart Fail. Rev.* 24 (5) (2019) 625–635.
- [18] J. Ternacle, M. Berry, T. Cognet, M. Kloeckner, T. Damy, J.L. Monin, J.P. Couetil, J. L. Dubois-Rande, P. Gueret, P. Lim, Prognostic value of right ventricular two-dimensional global strain in patients referred for cardiac surgery, *J. Am. Soc. Echocardiogr.* 26 (7) (2013) 721–726, <https://doi.org/10.1016/j.echo.2013.03.021>.
- [19] N. Alavi, W. Van Klei, K. Agyei, A. Zabida, M. Abraha, M. Salvatori, A. Mashari, J. Bartoszko, The association of right ventricular function with outcomes after cardiac surgery: a systematic review, *Can. J. Anaesth.* 72 (2) (2025) 285–318. English, <https://doi.org/10.1007/s12630-024-02898-9>.
- [20] M.A. Sabe, S.A. Sabe, K. Kusunose, S.D. Flamm, B.P. Griffin, D.H. Kwon, Predictors and prognostic significance of right ventricular ejection fraction in patients with ischemic cardiomyopathy, *Circulation* 134 (9) (2016) 656–665, <https://doi.org/10.1161/CIRCULATIONAHA.116.022339>.
- [21] A. Chrustowicz, A. Gackowski, N. El-Massri, J. Sadowski, W. Piwowarska, Preoperative right ventricular function in patients with organic mitral regurgitation, *Echocardiography* 27 (2010) 282–285.

- [22] G.E. Mandoli, M.C. Pastore, G. Benfari, M. Setti, D. Nistor, F. D'Ascenzi, M. Focardi, B. Baccani, G. Patti, S. Valente, S. Mondillo, M. Cameli, New echocardiographic indices of shift to biventricular failure to optimize risk stratification of chronic heart failure, *ESC Heart Fail.* 9 (1) (2022) 476–485, <https://doi.org/10.1002/ehf2.13722>.
- [23] A. Chrustowicz, G. Simonis, K. Matschke, R.H. Strasser, A. Gackowski, Right ventricular dilatation predicts survival after mitral valve repair in patients with impaired left ventricular systolic function, *Eur. J. Echocardiogr.* 10 (2) (2009) 309–313, <https://doi.org/10.1093/ejehocardi/jen247>.
- [24] M.C. Pastore, G.E. Mandoli, H.S. Aboumarie, C. Santoro, F. Bandera, A. D'Andrea, G. Benfari, R. Esposito, V. Evola, R. Sorrentino, P. Cameli, S. Valente, S. Mondillo, M. Galderisi, M. Cameli, Working Group of Echocardiography of the Italian Society of Cardiology, Basic and advanced echocardiography in advanced heart failure: an overview, *Heart Fail. Rev.* 25 (6) (2020 Nov) 937–948.
- [25] M. Cameli, M.C. Pastore, G.E. Mandoli, D. Nistor, E. Lisi, Ö.Ö. Tok, L. Cavigli, A. Romano, S. Mondillo, Prognosis and risk stratification of patients with advanced heart failure (from PROBE), *Am. J. Cardiol.* 124 (1) (2019 Jul 1) 55–62, <https://doi.org/10.1016/j.amjcard.2019.03.041>.
- [26] M. Cameli, H.S. Aboumarie, M.C. Pastore, K. Caliskan, M. Cikes, M. Garbi, H. S. Lim, D. Muraru, G.E. Mandoli, V. Pergola, S. Plein, G. Pontone, O.I. Soliman, P. Maurovich-Horvat, E. Donal, B. Cosyns, S.E. Petersen, Members of the 2022–2024 EACVI Scientific Documents Committee, Multimodality imaging for the evaluation and management of patients with long-term (durable) left ventricular assist devices, *Eur. Heart J. Cardiovasc. Imaging* 25 (10) (2024) e217–e240, <https://doi.org/10.1093/ehjci/jeae165>.
- [27] D. Bellavia, A. Iacovoni, C. Scardulla, L. Moja, M. Pilato, S.S. Kushwaha, M. Senni, F. Clemenza, V. Agnese, C. Falletta, G. Romano, J. Maalouf, M. Dandel, Prediction of right ventricular failure after ventricular assist device implant: systematic review and meta-analysis of observational studies, *Eur. J. Heart Fail.* 19 (7) (2017) 926–946, <https://doi.org/10.1002/ehf.733>.
- [28] R. Manganaro, S. Marchetta, R. Dulgheru, F. Ilardi, T. Sugimoto, S. Robinet, S. Cimino, Y.Y. Go, A. Bernard, G. Kacharava, G.D. Athanassopoulos, D. Barone, M. Baroni, N. Cardim, A. Hagendorff, K. Hristova, T. López-Fernández, G. de la Morena, B.A. Popescu, M. Penicka, T. Ozyigit, J.D. Rodrigo Carbonero, N. van de Veire, R.S. Von Bardeleben, D. Vinereanu, J.L. Zamorano, M. Rosca, A. Calin, M. Moonen, J. Magne, B. Cosyns, E. Galli, E. Donal, S. Carerj, C. Zito, C. Santoro, M. Galderisi, L.P. Badano, R.M. Lang, C. Oury, P. Lancellotti, Echocardiographic reference ranges for normal non-invasive myocardial work indices: results from the EACVI NORRE study, *Eur. Heart J. Cardiovasc. Imaging* 20 (5) (2019) 582–590, <https://doi.org/10.1093/ehjci/jej188>.
- [29] I. Yedidya, R.P. Lustosa, F. Fortuni, P. van der Bijl, F. Namazi, N.M. Vo, M. C. Meucci, N. Ajmone Marsan, J.J. Bax, V. Delgado, Prognostic implications of left ventricular myocardial work indices in patients with secondary mitral regurgitation, *Circ. Cardiovasc. Imaging* 14 (9) (2021) e012142, <https://doi.org/10.1161/CIRCIMAGING.120.012142>.
- [30] B. Bacchi, A. Stefanini, G.E. Mandoli, F. Lorusso, G. Toto, M.C. Pastore, F. Cabrucci, M. Bonacchi, M. Cameli, G. Bisleri, Right ventricle function: the role of the forgotten chamber in mitral valve surgery, *Curr. Cardiol. Rep.* 27 (1) (2025 Jan 9) 13, <https://doi.org/10.1007/s11886-024-02151-1>.