

Predictors of One-Year Restenosis After Percutaneous Mitral Balloon Valvuloplasty in Rheumatic Mitral Stenosis: Real-World Data From 555 Patients and the Limited Impact of Periinterventional Transesophageal Echocardiography

Romatizmal Mitral Darlığında Perkütan Mitral Balon Valvüloplasti Sonrası Bir Yıllık Restenozun Öngördürücüleri: 555 Hastalık Gerçek Yaşam Verisinde Periintervansiyonel Transözofageal Ekokardiyografinin Sınırlı Etkisi

ABSTRACT

Objective: Mitral balloon valvuloplasty remains an established first-line treatment for appropriately selected patients with rheumatic mitral stenosis. However, predictors of long-term restenosis and the additional value of periinterventional transesophageal echocardiography remain incompletely defined.

Method: This retrospective, single-center study included 555 patients who underwent percutaneous mitral balloon valvuloplasty for rheumatic mitral stenosis between January 2010 and January 2025 at Mehmet Akif Ersoy Heart Center, İstanbul, Türkiye. Patients were divided according to the presence or absence of restenosis at the 1-year follow-up. Restenosis was defined as a mitral valve area $<1.5 \text{ cm}^2$. Procedural success was defined as less than moderate mitral regurgitation at the end of the procedure and the absence of transeptal puncture-related complications. Clinical, echocardiographic, procedural, and laboratory variables were analyzed to identify predictors of restenosis and procedural success.

Results: Restenosis occurred in 94 patients (17%). The mean age of the overall cohort was 47.81 ± 12.29 years, and 467 patients (84.1%) were female. Patients with restenosis had higher preprocedural systolic pulmonary artery pressure, postprocedural transmitral gradient, postprocedural systolic pulmonary artery pressure, and preprocedural Wilkins score. In multivariable analysis, only the preprocedural Wilkins score remained an independent predictor of restenosis (OR: 1.907, 95% CI: 1.339–2.718, $P < 0.001$). Post-balloon transmitral gradient and postprocedural left atrial pressure $\geq 12 \text{ mmHg}$ were associated with procedural success. Periinterventional transesophageal echocardiography was not associated with restenosis or procedural success.

Conclusion: In patients undergoing percutaneous mitral balloon valvuloplasty for rheumatic mitral stenosis, the preprocedural Wilkins score was the only independent predictor of 1-year restenosis. Routine periinterventional transesophageal echocardiography did not significantly influence procedural success or long-term restenosis rates. These findings suggest that, in appropriately selected patients, percutaneous mitral balloon valvuloplasty can be safely and effectively performed under transthoracic echocardiographic guidance without routine periinterventional transesophageal echocardiography.

Keywords: Echocardiography, mitral valve, restenosis

ÖZET

Amaç: Mitral balon valvüloplasti, uygun şekilde seçilmiş romatizmal mitral darlığı hastalarında halen kabul görmüş birinci basamak tedavi seçeneğidir. Bununla birlikte, uzun dönem restenozun öngördürücüleri ve periintervansiyonel transözofageal ekokardiyografinin ek katkısı tam olarak tanımlanmamıştır.

Yöntem: Bu retrospektif, tek merkezli çalışmaya, Ocak 2010 ile Ocak 2025 tarihleri arasında İstanbul Mehmet Akif Ersoy Kalp Merkezi'nde romatizmal mitral darlığı nedeniyle perkütan

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Received: June 03, 2026

Accepted: August 22, 2026

Cite this article as: Aktemur Özalp T, Ukita K, Atmaca S, et al. Predictors of One-Year Restenosis After Percutaneous Mitral Balloon Valvuloplasty in Rheumatic Mitral Stenosis: Real-World Data From 555 Patients and the Limited Impact of Periinterventional Transesophageal Echocardiography. *Türk Kardiyol Dern Ars.* 2026;54(7):570-579.

DOI: 10.5543/tkda.2026.99527



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mitral balon valvüloplasti uygulanan 555 hasta dahil edildi. Hastalar, 1 yıllık takipte restenoz varlığına göre gruplara ayrıldı. Restenoz, mitral kapak alanının $<1,5 \text{ cm}^2$ olması olarak tanımlandı. İşlem başarısı, işlem sonunda mitral yetersizliğinin orta dereceden az olması ve transeptal ponksiyona bağlı komplikasyon gelişmemesi olarak tanımlandı. Restenozun ve işlem başarısının öngördürücülerini belirlemek amacıyla klinik, ekokardiyografik, işlemsel ve laboratuvar değişkenleri analiz edildi.

Bulgular: Restenoz 94 hastada (%17) görüldü. Tüm kohortun ortalama yaşı $47,81 \pm 12,29$ yıl olup 467 hasta (%84,1) kadındı. Restenoz gelişen hastalarda işlem öncesi sistolik pulmoner arter basıncı, işlem sonrası transmitral gradiyent, işlem sonrası sistolik pulmoner arter basıncı ve işlem öncesi Wilkins skoru daha yüksekti. Çok değişkenli analizde yalnızca işlem öncesi Wilkins skoru restenozun bağımsız öngördürücüsü olarak kaldı (OR=1,907; %95 GA: 1,339-2,718; $P < 0,001$). Balon sonrası transmitral gradiyent ve işlem sonrası sol atriyal basıncın $\geq 12 \text{ mmHg}$ olması işlem başarısı ile ilişkili bulundu. Perikardiyosentez transözofageal ekokardiyografi, restenoz veya işlem başarısı ile ilişkili değildi.

Sonuç: Romatizmal mitral darlığı nedeniyle perkütan mitral balon valvüloplasti uygulanan hastalarda işlem öncesi Wilkins skoru, 1 yıllık restenozun tek bağımsız öngördürücüsüydu. Rutin perikardiyosentez transözofageal ekokardiyografi, işlem başarısını veya uzun dönem restenoz oranlarını anlamlı ölçüde etkilemedi. Bu bulgular, uygun şekilde seçilmiş hastalarda perkütan mitral balon valvüloplastinin rutin perikardiyosentez transözofageal ekokardiyografi olmaksızın, transtoraks ekokardiyografi rehberliğinde güvenli ve etkili bir şekilde uygulanabileceğini düşündürmektedir.

Anahtar Kelimeler: Ekokardiyografi, mitral kapak, restenoz

Mitral stenosis remains a significant global health problem, particularly among younger patients in developing countries. Rheumatic heart disease is the most common underlying etiology, although mitral stenosis may also occur as a result of severe mitral annular calcification or, less frequently, other conditions such as congenital abnormalities, systemic inflammatory disease, carcinoid syndrome, or prior chest irradiation.^{1,2} Invasive treatment is indicated in symptomatic patients with severe mitral stenosis, and mitral balloon valvuloplasty is considered the first-line therapeutic option in appropriately selected cases.^{3,4} The outcomes of mitral balloon valvuloplasty are influenced by both patient-related characteristics and operator experience.^{5,6} The procedure is usually performed under the guidance of either transthoracic echocardiography (TTE) or transesophageal echocardiography (TEE); however, evidence regarding the additional benefit of TEE over TTE in terms of procedural success and restenosis remains limited. We aimed to identify predictors of restenosis following mitral balloon valvuloplasty, as well as determinants of procedural success and long-term outcomes, in patients treated at a high-volume tertiary referral center in İstanbul, Türkiye.

Materials and Methods

This retrospective study included 555 patients who underwent percutaneous mitral balloon valvuloplasty for rheumatic mitral valve stenosis between January 2010 and January 2025 at Mehmet Akif Ersoy Chest, Heart and Vascular Surgery Training and Research Hospital, İstanbul, Türkiye. The pooled data were analyzed retrospectively. The study was conducted in accordance with the Declaration of Helsinki and was approved by the İstanbul Mehmet Akif Ersoy Chest, Heart and Vascular Surgery Training and Research Hospital Scientific Research Ethics Committee (Approval Number: 2025.11-108, Date: 30.12.2025).

ABBREVIATIONS

ACEI	Angiotensin-converting enzyme inhibitor
AF	Atrial fibrillation
ARB	Angiotensin receptor blocker
ASA	Acetylsalicylic acid
AVA	Aortic valve area
CAD	Coronary artery disease
CI	Confidence interval
HR	Heart rate
LA	Left atrium
LAA	Left atrial appendage
LVEF	Left ventricular ejection fraction
MR	Mitral regurgitation
MVA	Mitral valve area
OR	Odds ratio
PAF	Paroxysmal atrial fibrillation
PAH	Pulmonary arterial hypertension
PHT	Pressure half time
SEK	Spontaneous echo contrast
SPAP	Systolic pulmonary artery pressure
TEE	Transesophageal echocardiography
TMG	Transmitral gradient
TTE	Transthoracic echocardiography

Data Collection

Demographic characteristics, comorbidities, electrocardiographic findings, hospitalization data, pericardial data, peri- and postinterventional echocardiographic parameters, and laboratory values were obtained from electronic medical records. These parameters were compared between patients with long-term restenosis and those without restenosis. The decision not to use TEE in selected patients was based on adequate transthoracic image quality, an increased risk associated with general

Table 1. Baseline characteristics of the patients

Variables	All patients (n=555)	No restenosis (n=461)	Restenosis (n=94)	P
Age, years	47.81±12.29	48.12±12.54	46.28±10.96	0.185
Sex				
Female	467 (84.1)	382 (82.9)	85 (90.4)	0.054
Complaints				0.780
Dyspnea	430 (77.5)	359 (77.9)	71 (75.5)	
Dyspnea and palpitations	33 (5.9)	26 (5.6)	7 (7.4)	
Other	92 (16.0)	76 (16.5)	16 (17.0)	
Diabetes mellitus	48 (8.6)	39 (8.5)	9 (9.6)	0.729
Arterial hypertension	110 (19.8)	94 (20.4)	16 (17.0)	0.570
Hyperlipidemia	75 (13.5)	65 (14.1)	10 (10.6)	0.358
Pregnancy during the procedure	7 (1.3)	7 (1.5)	0 (0)	0.609
Ischemic cerebrovascular event	21 (3.8)	17 (3.7)	4 (4.3)	0.767
Thyroid dysfunction	30 (5.4)	23 (5.0)	7 (7.4)	0.349
CAD >50% stenosis	13 (2.3)	11 (2.4)	2 (2.1)	0.887
PAH	4 (0.8)	3 (0.6)	1 (1.1)	0.523

Values are presented as n (%), mean±SD, or median (first quartile, third quartile), as appropriate. CAD, Coronary artery disease; PAH, Pulmonary arterial hypertension.

anesthesia due to concomitant respiratory disease, and the patient's preference to avoid general anesthesia.

Endpoints

The following endpoints were defined in this study.

Primary Outcome

The primary endpoint was restenosis, defined as a mitral valve area of less than 1.5 cm² at the 1-year follow-up.

Secondary Outcome

The secondary endpoint was procedural success. Procedural success was defined as less than moderate mitral valve regurgitation at the end of the procedure and the absence of transseptal puncture-related complications, such as cardiac tamponade.

Statistical Analysis

Categorical variables were presented as absolute frequencies and percentages. Continuous variables were expressed as mean±standard deviation or median with interquartile range, according to their distribution. Normality was assessed using the Kolmogorov-Smirnov test and visual inspection of histograms. Between-group comparisons were performed using the independent-samples Student's t-test or the Mann-Whitney U test for continuous variables, as appropriate. Categorical variables were compared using Pearson's chi-square test or Fisher's exact test.

Procedural outcome and 1-year restenosis were defined and analyzed as two separate study endpoints. Patients were first compared according to procedural success, and a separate analysis was subsequently performed according to the presence or absence of restenosis at 1 year. To identify independent factors associated with procedural failure, univariable logistic regression analyses were initially performed. Variables considered clinically relevant and those showing a p value <0.10

in the univariable analyses were entered into a multivariable binary logistic regression model. A separate multivariable binary logistic regression model was constructed to identify independent predictors of 1-year restenosis. Periinterventional TEE was evaluated separately in both models to determine its adjusted association with procedural outcome and 1-year restenosis. The results of the logistic regression analyses were reported as odds ratios with corresponding 95% confidence intervals. P values and confidence intervals were calculated using the Wald method. Multicollinearity was assessed before construction of the multivariable models. All statistical tests were two-sided, and a p value <0.05 was considered statistically significant. Data preparation and statistical analyses were performed using IBM SPSS Statistics for Windows, version 25.0 (IBM Corp., Armonk, NY, USA).

Results

The baseline characteristics of the patients are summarized in Table 1. Among the 555 patients, restenosis occurred in 94 (17%). The mean age of the overall cohort was 47.81±12.29 years, and 467 patients (84.1%) were female. The proportion of female patients was higher in the restenosis group than in the non-restenosis group [90.4% vs. 82.9%, P = 0.054]; however, this difference was not statistically significant. All other baseline characteristics and comorbidities were comparable between the two groups. Preprocedural medications are summarized in Table 2. Patients with restenosis used diuretics more frequently than those without restenosis [67 (71.3%) vs. 273 (59.2%), P = 0.029]. The use of acetylsalicylic acid was also higher in patients with restenosis [56 (59.6%) vs. 223 (48.4%), P = 0.048]. The use of other medications was comparable between the two groups. Electrocardiographic parameters are summarized in Table 3. The prevalence of atrial fibrillation and postprocedural heart rate were comparable between the groups.

Table 2. Preprocedural medications of the patients

Medication	All patients (n=555)	No restenosis (n=461)	Restenosis (n=94)	P
Statin	42 (7.6)	38 (8.2)	4 (4.3)	0.159
Diuretics	340 (61.3)	273 (59.2)	67 (71.3)	0.029
Beta-blocker	430 (77.5)	354 (76.8)	76 (80.9)	0.390
ASA	279 (50.3)	223 (48.4)	56 (59.6)	0.048
Warfarin	181 (32.6)	144 (31.2)	37 (39.4)	0.126
Antiarrhythmics				0.818
Amiodarone	8 (1.4)	7 (1.5)	1 (1.1)	
Propafenone	3 (0.5)	3 (0.6)	0 (0)	
Sotalol	1 (0.2)	1 (0.2)	0 (0)	
Calcium channel blockers				0.106
Non-dihydropyridine	29 (5.2)	20 (4.3)	9 (9.6)	
Dihydropyridine	16 (2.9)	14 (3.0)	2 (2.1)	
Digoxin	24 (4.3)	18 (3.9)	6 (6.4)	0.268
ACEI/ARB	91 (16.4)	77 (16.7)	14 (14.9)	0.666

Values are presented as n (%), mean±SD, or median (first quartile, third quartile), as appropriate. ASA, Acetylsalicylic acid; ACEI, Angiotensin-converting enzyme inhibitor; ARB, Angiotensin receptor blocker.

Table 3. Electrocardiographic parameters of the patients

Parameters	All patients (n=555)	No restenosis (n=461)	Restenosis (n=94)	P
Preprocedural ECG				0.604
Sinus rhythm	422 (76.0)	354 (76.8)	68 (72.3)	
AF	104 (19.0)	86 (18.7)	18 (19.1)	
Pacemaker rhythm	3 (0.5)	2 (0.4)	1 (1.1)	
PAF	23 (4.1)	17 (3.7)	6 (6.4)	
Preprocedural HR	78.38±17.53	77.66±16.86	81.86±20.76	0.221
PR interval (ms)	157.59±29.73	158.04±29.24	155.32±32.24	0.942
QRS duration (ms)	80.41±13.56	80.57±13.97	79.65±11.65	0.660
QTc interval (ms)	436.05±34.01	434.98±34.15	441.34±33.54	0.244
Postprocedural ECG				0.072
Sinus rhythm	426 (76.8)	360 (78.1)	66 (70.2)	
AF	117 (21.1)	94 (20.4)	23 (24.5)	
Pacemaker rhythm	3 (0.5)	2 (0.4)	1 (1.1)	
PAF	4 (0.7)	3 (0.7)	1 (1.1)	
Postprocedural HR	78.94±17.04	79.03±17.00	73.61±16.10	0.493
PR interval (ms)	156.46±29.16	156.56±28.34	155.85±33.52	0.593
QRS duration (ms)	82.19±32.87	80.47±12.91	90.66±73.39	0.258
QTc interval (ms)	440.99±35.21	440.54±33.65	442.46±42.04	0.754

Values are presented as n (%), mean±SD, or median (first quartile, third quartile), as appropriate. ECG, Electrocardiography; AF, Atrial fibrillation; PAF, Paroxysmal atrial fibrillation; HR, Heart rate; ms, Milliseconds.

Echocardiographic parameters are summarized in Table 4. Regarding preprocedural TTE findings, systolic pulmonary artery pressure (SPAP) was significantly higher in the restenosis group [47.47±15.23 vs. 43.65±15.79 mmHg, $P = 0.011$]. Moderate aortic stenosis before the procedure was also more frequent in the restenosis group [4 (4.3%) vs. 6 (1.3%), $P = 0.033$]. Regarding postprocedural TTE findings, the transmitral gradient

(TMG) was higher in patients with restenosis [5.85±2.28 vs. 5.23±2.07 mmHg, $P = 0.005$]. Postprocedural SPAP was also significantly higher in the restenosis group [36.51±10.31 vs. 33.80±9.50 mmHg, $P = 0.010$]. Regarding TEE findings, only the preprocedural Wilkins score was significantly higher in the restenosis group [7.91±1.18 vs. 7.41±1.27, $P = 0.001$]. Other TEE findings were comparable between the groups.

Table 4. Echocardiographic parameters of the patients

Parameters	All patients (n=555)	No restenosis (n=461)	Restenosis (n=94)	P
Preprocedural LVEF	61.31±4.25	61.31±4.15	61.27±4.76	0.955
Preprocedural LA diameter	4.61±2.01	4.62±2.20	4.48±0.43	0.083
Preprocedural SPAP (TTE)	44.32±15.76	43.65±15.79	47.47±15.23	0.011
MR >grade I	156 (28.1)	131 (28.4)	25 (26.6)	0.720
TTE Wilkins score	7.86±1.49	7.81±1.57	8.02±1.08	0.654
Preprocedural MVA, planimetric (TTE)	1.20±1.37	1.21±1.51	1.13±0.22	0.828
Preprocedural MVA, PHT (TTE)	1.16±0.21	1.16±0.21	1.14±0.23	0.421
Preprocedural TMG (TTE)	11.36±4.74	11.25±4.61	11.93±5.34	0.282
Aortic valve stenosis				0.033
Mild	15 (2.7)	15 (3.3)	0 (0)	
Moderate	10 (1.8)	6 (1.3)	4 (4.3)	
Postprocedural LVEF	61.11±4.68	61.02±4.36	61.48±4.92	0.210
Postprocedural LA diameter	4.28±0.53	4.25±0.53	4.39±0.51	0.012
Postprocedural SPAP (TTE)	34.27±9.69	33.80±9.50	36.51±10.31	0.010
MR >grade I	203 (36.6)	167 (36.3)	36 (38.3)	0.713
Postprocedural MVA, planimetric (TTE)	1.81±0.34	1.82±0.33	1.79±0.38	0.896
Postprocedural MVA, PHT (TTE)	1.80±0.32	1.80±0.33	1.79±0.27	0.651
Postprocedural TMG (TTE)	5.34±2.12	5.23±2.07	5.85±2.28	0.005
Preprocedural SPAP (TEE)	48.85±15.88	48.54±15.67	50.43±16.95	0.169
Preprocedural MV mean gradient (TEE)	13.16±5.77	13.07±5.75	13.77±5.92	0.164
Preprocedural MVA, 3D (TEE)	1.08±0.57	1.10±0.63	1.01±0.25	0.131
Preprocedural MVA, PHT (TEE)	1.11±0.19	1.12±0.19	1.09±0.20	0.137
Preprocedural 3D MPR MVA (TEE)	1.15±0.34	1.16±0.34	1.05±0.34	0.137
LAA velocity (cm/s)	34.25±15.08	33.34±15.09	36.77±14.98	0.198
LAA thrombus or SEC				0.236
LAA thrombus	27 (4.9)	24 (5.2)	3 (3.2)	
LA SEC	73 (13.2)	56 (12.1)	17 (18.1)	
Preprocedural Wilkins score (TEE)	7.49±1.27	7.41±1.27	7.91±1.18	0.001

Values are presented as n (%), mean±SD, or median (first quartile, third quartile), as appropriate. LVEF, Left ventricular ejection fraction; TTE, Transthoracic echocardiography; TEE, Transesophageal echocardiography; SPAP, Systolic pulmonary artery pressure; MR, Mitral regurgitation; MVA, Mitral valve area; TMG, Transmitral gradient; PHT, Pressure half-time; MV, Mitral valve; LA, Left atrium; LAA, Left atrial appendage; SEC, Spontaneous echo contrast; 3D, Three-dimensional; MPR, Multiplanar reconstruction.

Procedural success was also analyzed. Baseline characteristics according to procedural success are summarized in Table 5. Among the 555 patients, 51 had unsuccessful procedures. The reasons for procedural failure were severe mitral regurgitation in 16 patients (31.4%), pericardial effusion or tamponade in 11 patients (21.6%), failed atrial septostomy in 9 patients (17.6%), left atrial thrombus in 6 patients (11.8%), and other causes, including severe peripheral complications and severe pulmonary edema, in 9 patients (17.6%). Patients with unsuccessful procedures were significantly older than those with successful procedures [51.98±12.50 vs. 47.35±12.22 years, $P = 0.010$]. Other baseline parameters, including sex, preexisting hypertension, diabetes mellitus, coronary artery disease, and pulmonary arterial hypertension, were comparable between the two groups. Procedural characteristics, including contrast volume, procedure duration, and the use of TEE guidance, were also similar. The number of balloon inflations was lower in the

unsuccessful procedure group [1.29±0.89 vs. 2.00±0.72, $P = 0.001$]. The length of hospital stay was significantly longer in patients with unsuccessful procedures [7.06±6.71 vs. 3.01±1.75 days, $P < 0.001$]. Electrocardiographic and echocardiographic parameters according to procedural success are summarized in Table 6. Preprocedural heart rate was higher in the unsuccessful procedure group [86.18±22.38 vs. 77.56±16.89 bpm, $P = 0.018$]. Both preprocedural and postprocedural SPAPs were significantly higher in the unsuccessful procedure group ($P < 0.001$ and $P = 0.001$, respectively). Preprocedural TEE parameters were comparable between the groups, except for the presence of left atrial appendage thrombus or spontaneous echo contrast, which was significantly more frequent in patients with unsuccessful procedures ($P < 0.001$).

Outcomes

The primary outcome was restenosis. Univariable (Table 7) and multivariable (Table 8) analyses were performed to determine

Table 5. Baseline analysis according to procedural success

Variables	Successful (n=504)	Unsuccessful (n=51)	P
Age, years	47.35±12.22	51.98±12.50	0.010
Female sex	420 (83.3)	47 (92.2)	0.100
Complaints			0.472
Dyspnea	388 (77.0)	42 (82.4)	
Dyspnea and palpitations	30 (6.0)	3 (5.9)	
Other (edema, etc.)	66 (13.1)	3 (5.9)	
Diabetes mellitus	44 (8.7)	4 (7.8)	0.830
Hypertension	101 (20.0)	9 (17.5)	0.683
Hyperlipidemia	68 (13.5)	7 (13.7)	0.963
Pregnancy during the procedure	7 (1.4)	0 (0)	0.397
CVE	18 (3.6)	3 (5.9)	0.410
Thyroid dysfunction	25 (5.0)	5 (9.8)	0.145
CAD >50% stenosis	12 (2.4)	1 (2.0)	0.850
PAH	4 (0.8)	0 (0)	0.523
Diuretics	307 (60.9)	33 (64.7)	0.596
Beta-blocker	395 (78.4)	35 (68.6)	0.112
TEE-guided procedure	340 (71.3)	33 (76.7)	0.446
Procedure duration (min)	85.19±37.16	96.90±54.30	0.405
Fluoroscopy duration (min)	25.83±25.52	27.32±18.74	0.448
Radiation dose (mGy)	5749.43±587.36	477.86±353.42	0.736
Contrast volume (mL)	50.55±40.79	51.67±38.70	0.999
Balloon diameter (mm)	27.88±1.26	27.56±0.82	0.114
Number of balloon inflations	2.00±0.72	1.29±0.89	0.001
LA pressure before balloon inflation (mmHg)	12.69±5.09	15.50±9.01	0.581
LA pressure after balloon inflation (mmHg)	4.71±2.23	6.75±4.13	0.068
Postprocedural CVE	1 (0.2)	0 (0)	0.750
Postprocedural pericardial effusion (no intervention required)	7 (1.4)	3 (5.9)	0.022
Reason for procedural failure			0.730
Severe MR	—	16 (31.4)	
Pericardial effusion/pericardial tamponade	—	11 (21.6)	
Failed atrial septostomy	—	9 (17.6)	
Left atrial thrombus	—	6 (11.8)	
Other	—	9 (17.6)	
Length of hospital stay (days)	3.01±1.75	7.06±6.71	<0.001

Values are presented as n (%), mean±SD, or median (first quartile, third quartile), as appropriate. CAD, Coronary artery disease; PAH, Pulmonary arterial hypertension; CVE, Cerebrovascular event; MR, Mitral regurgitation; LA, Left atrium; TEE, Transesophageal echocardiography.

predictors of restenosis. After adjustment for all relevant factors, only the preprocedural Wilkins score remained an independent predictor of restenosis [OR: 1.907, 95% CI: 1.339–2.718, $P < 0.001$].

The secondary outcome was procedural success. Univariable (Table 9) and multivariable (Table 10) analyses were performed to determine predictors of procedural success. Preprocedural transmitral gradient [OR: 1.156, 95% CI: 1.178–12.181, $P = 0.003$] and greater than mild mitral regurgitation [OR: 3.788, 95% CI: 1.020–1.311, $P = 0.025$] were associated with procedural success.

In this cohort, periinterventional TEE was not significantly associated with either procedural success or 1-year restenosis.

Discussion

In the present study, we evaluated predictors of long-term restenosis and procedural success in patients undergoing percutaneous mitral balloon valvuloplasty. The main findings of our study were as follows: first, the preprocedural Wilkins score was the only independent predictor of long-term restenosis after adjustment for potential confounders; second, the use of periinterventional TEE was not associated with a significant difference in procedural success or long-term restenosis; and third, comprehensive preprocedural imaging remains essential for optimal patient selection, anatomical assessment, and procedural planning.

Table 6. Electrocardiographic and echocardiographic analysis according to procedural success

Parameters	Successful (n=504)	Unsuccessful (n=51)	P
Preprocedural ECG			0.063
Sinus rhythm	390 (77.4)	32 (62.7)	
Permanent AF	89 (17.7)	15 (29.4)	
Pacemaker rhythm	2 (0.4)	1 (2.0)	
Paroxysmal AF/persistent AF	21 (4.2)	2 (3.9)	
Preprocedural HR (bpm)	77.56±16.89	86.18±22.38	0.018
PR interval (ms)	157.36±28.34	159.87±41.35	0.113
QRS duration (ms)	80.46±13.63	79.89±13.37	0.708
QTc interval (ms)	434.77±33.68	448.57±35.97	0.018
Postprocedural ECG			0.213
Sinus rhythm	392 (77.8)	34 (66.7)	
Permanent AF/persistent AF	103 (20.4)	14 (27.5)	
Pacemaker rhythm	2 (0.4)	1 (2.0)	
Paroxysmal AF	3 (0.6)	1 (2.0)	
Postprocedural HR (bpm)	78.14±16.48	84.60±16.40	0.019
Postprocedural QTc interval (ms)	439.48±34.16	455.25±42.53	0.007
Preprocedural LVEF (%)	61.26±4.35	61.71±3.11	0.662
Preprocedural LA diameter (cm)	4.61±2.10	4.66±0.63	0.162
Preprocedural SPAP (mmHg)	43.74±15.93	49.43±12.96	0.001
MR >mild	135 (26.8)	21 (41.2)	0.029
Preprocedural TTE Wilkins score	7.79±1.52	8.42±1.07	0.108
Preprocedural planimetric MVA (TTE) (cm ²)	1.21±1.45	1.10±0.19	0.212
Preprocedural MVA by PHT (TTE) (cm ²)	1.16±0.21	1.11±0.19	0.169
Preprocedural TMG (TTE) (mmHg)	11.23±4.70	12.66±5.02	0.029
Aortic valve stenosis			0.940
Mild AVS	14 (2.8)	1 (2.0)	
Moderate AVS	9 (1.8)	1 (2.0)	
Postprocedural LVEF (%)	61.22±4.26	58.88±7.15	0.085
Postprocedural LA pressure (mmHg)	4.26±0.53	4.49±0.49	0.052
Postprocedural SPAP (mmHg)	33.86±9.36	42.19±12.52	0.001
Postprocedural planimetric MVA (TTE) (cm ²)	1.82±0.34	1.67±0.45	0.146
Postprocedural MVA by PHT (TTE) (cm ²)	1.80±0.31	1.67±0.46	0.477
Postprocedural TMG (TTE) (mmHg)	5.24±1.95	7.295±3.87	0.012
Preprocedural SPAP (TEE) (mmHg)	48.67±15.71	50.63±17.54	0.329
Preprocedural TMG (TEE) (mmHg)	13.09±5.82	14.16±5.29	0.091
Preprocedural planimetric MVA (TEE) (cm ²)	1.08±0.61	1.08±0.22	0.402
Preprocedural MVA by PHT (TEE) (cm ²)	1.12±0.19	1.09±0.18	0.415
Preprocedural MVA by 3D TEE (cm ²)	1.15±0.35	1.11±0.26	0.560
LAA velocity (cm/s)	34.64±15.77	31.88±9.94	0.726
LAA thrombus/SEC			0.003
LAA thrombus	19 (3.8)	8 (15.7)	
LA SEC	64 (12.7)	9 (17.6)	
Preprocedural Wilkins score (TEE)	7.48±1.27	7.61±1.31	0.527

Values are presented as n (%), mean±SD, or median (first quartile, third quartile), as appropriate. ECG, Electrocardiography; AF, Atrial fibrillation; HR, Heart rate; bpm, Beats per minute; ms, Milliseconds; LVEF, Left ventricular ejection fraction; TTE, Transthoracic echocardiography; TEE, Transesophageal echocardiography; SPAP, Systolic pulmonary artery pressure; MR, Mitral regurgitation; MVA, Mitral valve area; TMG, Transmitral gradient; PHT, Pressure half-time; AVS, Aortic valve stenosis; LA, Left atrium; LAA, Left atrial appendage; SEC, Spontaneous echo contrast; 3D, Three-dimensional.

Table 7. Univariable regression analysis of predictors of long-term restenosis

Parameters	P	OR	95% CI
Preprocedural diuretic use	0.030	1.709	1.053–2.772
ASA use	0.049	1.573	1.002–2.468
LA pressure before MBV	0.015	1.071	1.014–1.132
LA pressure after MBV	0.020	1.149	1.022–1.292
Preprocedural SPAP (TTE)	0.048	1.014	1.001–1.026
Aortic valve stenosis (AVA <1.5 cm ²)	0.450	1.279	0.675–2.425
Postprocedural LA diameter	0.025	1.640	1.065–2.525
Postprocedural SPAP (TTE)	0.030	1.028	1.003–1.053
Postprocedural TMG	0.015	1.131	1.024–1.249
Preprocedural Wilkins score (TEE)	0.002	1.364	1.125–1.654
Triglycerides	0.050	0.992	0.989–1.000
INR	0.050	0.413	0.174–1.001

OR, Odds ratio; CI, Confidence interval; ASA, Acetylsalicylic acid; LA, Left atrium; MBV, Mitral balloon valvuloplasty; SPAP, Systolic pulmonary artery pressure; AVA, Aortic valve area; TTE, Transthoracic echocardiography; TMG, Transmitral gradient; TEE, Transesophageal echocardiography; INR, International normalized ratio.

Table 8. Multivariable regression analysis of predictors of long-term restenosis

Parameters	P	OR	95% CI
Preprocedural diuretic use	0.208	1.700	0.745–3.880
ASA use	0.111	1.902	0.863–4.194
LA pressure after MBV	0.634	1.039	0.888–1.216
Preprocedural SPAP (TTE)	0.779	1.003	0.982–1.025
LA pressure after MBV	0.202	1.610	0.774–3.351
Postprocedural SPAP (TTE)	0.779	1.003	0.982–1.025
Postprocedural TMG	0.076	1.202	0.982–1.471
Preprocedural Wilkins score (TEE)	<0.001	1.907	1.339–2.718

OR, Odds ratio; CI, Confidence interval; ASA, Acetylsalicylic acid; LA, Left atrium; MBV, Mitral balloon valvuloplasty; SPAP, Systolic pulmonary artery pressure; TTE, Transthoracic echocardiography; TMG, Transmitral gradient; TEE, Transesophageal echocardiography.

Percutaneous mitral balloon valvuloplasty remains an effective and well-established treatment option for selected patients with rheumatic mitral stenosis.^{3,4} The success and durability of the procedure are strongly influenced by mitral valve morphology, including leaflet mobility, leaflet thickening, calcification, and subvalvular involvement. These anatomical features are reflected in the Wilkins score, which has been widely used for preprocedural risk stratification and patient selection.⁷⁻¹⁰ In our study, the preprocedural Wilkins score was significantly higher in patients who developed restenosis and remained the only independent predictor of long-term restenosis in multivariable analysis. This finding supports the concept that the structural condition of the mitral valve before intervention is a major determinant of long-term valve durability after balloon valvuloplasty. In our cohort, several echocardiographic parameters differed between patients with and without restenosis. Preprocedural SPAP was higher in the

restenosis group, and postprocedural transmitral gradient and SPAP were also significantly higher in patients who developed restenosis. These findings suggest that patients with restenosis may have a greater hemodynamic burden both before and after the procedure. However, after adjustment, these parameters did not remain independent predictors of restenosis. This indicates that although hemodynamic variables reflect disease severity, anatomical valve morphology, as assessed by the Wilkins score, may have greater prognostic value for long-term restenosis.

Another important finding of our study was that periinterventional TEE did not significantly affect procedural success or long-term restenosis rates. TEE is commonly used before balloon valvuloplasty to exclude left atrial or left atrial appendage thrombus, assess mitral regurgitation, and provide additional anatomical information. It may also facilitate transseptal puncture by improving visualization of the interatrial septum and guiding catheter positioning, and several studies have suggested advantages of echocardiographic guidance over fluoroscopy alone in this setting.^{11,12} However, our findings suggest that the routine use of periinterventional TEE does not necessarily translate into improved procedural outcomes related to transseptal puncture or lower long-term restenosis rates. This may be explained by the fact that restenosis after balloon valvuloplasty is mainly driven by baseline valve morphology, rheumatic disease progression, commissural fusion, calcification, and subvalvular involvement rather than by the intraprocedural imaging strategy alone. Therefore, while preprocedural TEE remains essential for appropriate patient selection, exclusion of left atrial thrombus, assessment of mitral regurgitation, and identification of unfavorable anatomical features, routine periinterventional TEE may not provide additional benefit in all patients. In carefully selected cases with favorable anatomy and adequate transthoracic imaging quality, periinterventional guidance with TTE may be considered. This approach may also be relevant in patients for whom general anesthesia or deep sedation could carry additional risk, such as those with chronic obstructive pulmonary disease or significant comorbidities. Nevertheless, periinterventional TEE should remain available and should be used selectively in patients with complex anatomy, suboptimal transthoracic imaging, uncertain procedural findings, or increased safety concerns.

The role of TTE is also central to the evaluation of patients with mitral stenosis. TTE provides essential information regarding mitral valve area, transmitral gradient, pulmonary artery pressure, left atrial size, right ventricular function, and associated valvular lesions. In our study, preprocedural and postprocedural TTE parameters provided important clinical and hemodynamic information. In particular, higher postprocedural transmitral gradients and higher postprocedural SPAPs were observed in patients who subsequently developed restenosis. These parameters may help identify patients who require closer follow-up after balloon valvuloplasty, even if they do not independently predict restenosis after multivariable adjustment. From a clinical perspective, patients with higher preprocedural Wilkins scores should be considered at increased risk for long-term restenosis.^{3,4,10} These patients may benefit from more careful counseling before the procedure, closer echocardiographic follow-up, and earlier consideration of alternative treatment strategies when valve anatomy is unfavorable. Although balloon

Table 9. Univariable regression analysis of procedural success

Parameters	P	OR	95% CI
Age	0.011	1.031	1.007-1.055
Sex	0.110	2.350	0.825-6.698
Diabetes mellitus	0.830	0.890	0.306-2.585
Hypertension	0.683	0.855	0.403-1.814
Hyperlipidemia	0.963	1.020	0.441-2.357
Procedure duration	0.193	1.007	0.996-1.018
Fluoroscopy duration	0.835	1.002	0.982-1.022
Balloon diameter	0.194	0.826	0.620-1.102
Number of balloon inflations	<0.001	0.267	0.149-0.480
Preprocedural heart rate	0.005	1.023	1.007-1.040
Preprocedural SPAP (TTE)	0.020	1.020	1.003-1.036
MR >mild	0.032	1.913	1.059-3.457
LAA thrombus/SEC	0.004	1.593	1.163-2.180
TEE-guided procedure	0.447	1.330	0.638-2.772
Preprocedural LA pressure	0.143	1.082	0.974-1.202
Preprocedural LVEF	0.479	1.027	0.953-1.107
Preprocedural planimetric MVA (TTE) (cm ²)	0.171	0.366	0.087-1.542
Preprocedural MVA by PHT (TTE) (cm ²)	0.133	0.348	0.088-1.380
Preprocedural TMG	0.046	1.057	1.001-1.116
Preprocedural SPAP (TEE) (mmHg)	0.427	1.007	0.989-1.026
Preprocedural TMG (TEE)	0.221	1.031	0.982-1.082
Preprocedural planimetric MVA (TEE) (cm ²)	0.995	1.002	0.593-1.692
Preprocedural MVA by PHT (TEE) (cm ²)	0.390	0.505	0.106-2.397
Preprocedural 3D MVA (TEE) (cm ²)	0.662	0.663	0.105-4.193
LAA velocity	0.496	0.987	0.950-1.025
Preprocedural Wilkins score (TEE)	0.537	1.078	0.848-1.371

CI, Confidence interval; OR, Odds ratio; SPAP, Systolic pulmonary artery pressure; TTE, Transthoracic echocardiography; TEE, Transesophageal echocardiography; MR, Mitral regurgitation; LAA, Left atrial appendage; SEC, Spontaneous echo contrast; LA, Left atrium; LVEF, Left ventricular ejection fraction; MVA, Mitral valve area; PHT, Pressure half-time; TMG, Transmitral gradient; 3D, Three-dimensional.

Table 10. Multivariable regression analysis of procedural success

Parameters	P	OR	95% CI
Age	0.265	1.026	0.980-1.075
Number of balloon inflations	0.078	0.526	0.257-1.074
Preprocedural heart rate	0.378	1.013	0.985-1.041
Preprocedural QTc interval	0.247	1.009	0.994-1.025
Preprocedural SPAP	0.396	1.015	0.980-1.052
MR >mild	0.025	3.788	1.178-12.181
LAA thrombus/SEC	0.594	0.801	0.354-1.813
Preprocedural TMG (mmHg)	0.003	1.156	1.020-1.311

CI, Confidence interval; OR, Odds ratio; SPAP, Systolic pulmonary artery pressure; MR, Mitral regurgitation; LAA, Left atrial appendage; SEC, Spontaneous echo contrast; TMG, Transmitral gradient.

valvuloplasty may still provide symptomatic and hemodynamic improvement in selected patients with relatively high Wilkins scores, the expected durability of the procedure should be interpreted with caution.

This study has several limitations. First, it was a retrospective, single-center study, which may limit the generalizability of the findings. Second, although the overall cohort size was acceptable, the number of patients with restenosis was relatively limited, which may reduce the statistical power of the multivariable analysis. Third, the decision to perform periinterventional TEE may have been influenced by operator preference, patient characteristics, or image quality, introducing potential selection bias. Finally, long-term follow-up beyond 1 year would provide more comprehensive information regarding the progression of restenosis and clinical outcomes.

In this large real-world cohort of patients undergoing percutaneous mitral balloon valvuloplasty for rheumatic mitral stenosis, baseline mitral valve morphology, as assessed by the Wilkins score, was the main determinant of 1-year restenosis. Routine periinterventional TEE was not significantly associated with procedural success or restenosis in this cohort, suggesting that its use may be best considered on an individualized basis rather than as a routine requirement for all patients.

Ethics Committee Approval: Ethics committee approval was obtained from İstanbul Mehmet Akif Ersoy Chest, Heart and Vascular Surgery Training and Research Hospital Scientific Research Ethics Committee (Approval Number: 2025.11-108, Date: 30.12.2025).

Informed Consent: Written informed consent was obtained from the patients.

Conflict of Interest: The authors have no conflicts of interest to declare.

Funding: The authors declared that this study received no financial support.

Use of AI for Writing Assistance: The authors declare ChatGPT was used in order to improve language during the preparation of this work. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Author Contributions: Concept – T.A.Ö., İ.F.A.; Design – T.A.Ö., C.Y.; Supervision – M.E., İ.F.A.; Data Collection and/or Processing – S.A., E.M., D.P., Y.K.; Analysis and/or Interpretation – T.A.Ö., C.Y.; Literature Review – T.A.Ö.; Writing – T.A.Ö., K.U., C.Y., İ.F.A.; Critical Review – K.U.

Peer-review: Externally peer-reviewed.

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