ORIGINAL ARTICLE

# Differences in Mitral Valve Geometry between Atrial and Ventricular Functional Mitral Regurgitation in Patients with Atrial Fibrillation: a 3D Transesophageal Echocardiography Study

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Abstract

*Background:* **Functional mitral regurgitation (FMR) is commonly attributed to either atrial or ventricular dysfunction.**
*Objective:* **This study aimed to investigate mitral valve geometric differences between atrial functional mitral regurgitation (A-FMR) and ventricular functional mitral regurgitation (V-FMR) using three-dimensional transesophageal echocardiography (3D-TEE).**
*Patients and Methods:* **The study included 50 patients with non-valvular atrial fibrillation who had a clinical indication for echocardiography. These patients were classified into two groups based on the etiology of FMR: atrial and ventricular types. All patients visited the ECHO lab at Bab Al-Sharia Hospital, Al-Azhar University, between April 2023 and January 2025.**
*Results:* **No significant differences were observed between the A-FMR and V-FMR groups in terms of effective regurgitant orifice area, regurgitation volume, or vena contracta width. However, the left atrium (LA) diameter was significantly larger in the V-FMR group (p=0.027). Additionally, the left ventricular end-systolic volume (LV-ESV) index and ejection fraction (EF) showed significant differences (p=0.001). While no significant differences were found in the anterior mitral leaflet (AML) and posterior mitral leaflet (PML) areas, the posterior mitral leaflet angles (central, lateral, and medial) differed significantly (p=0.001, 0.002, and 0.001, respectively). Mitral valve tenting volume and height also demonstrated significant differences (p=0.001 and 0.002, respectively).**
*Conclusion:* **This study compared mitral valve features in atrial and ventricular functional mitral regurgitation. While both groups shared common characteristics, distinct differences were observed in left atrial diameter and mitral leaflet tethering, highlighting the importance of etiology-specific evaluation in FMR.**

*Keywords:* FMR; TEE; LV

## 1. Introduction

MR is usually attributed to global or local LV dysfunction and remodeling in the absence of structural MV abnormalities.[1] Global or local left ventricular dysfunction and remodeling lead to papillary muscle displacement and mitral leaflet tethering, ultimately leading to decreased leaflet coaptation.[2] Long-standing atrial fibrillation can lead to left atrium enlargement and mitral annular dilatation. Mitral annular dilatation significantly contributes to the onset of A-FMR.[3]

Currently, additional factors, including inadequate leaflet remodeling, tethering of the PML, reduced annular contractility, and the flattening of the annular saddle shape, have been identified as related to the development of atrial functional mitral regurgitation.[4]

The exact mechanism of atrial functional mitral regurgitation remains unclear. Real-time 3D transesophageal echocardiography (TOE) provides precise data regarding the mitral valve apparatus. Throughout the years, the mitral valve geometry in cases of major atrial functional MR and non-significant atrial functional MR, as well as in healthy persons with sinus rhythm, has been analyzed utilizing three-dimensional transesophageal echocardiography.[5]

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To our knowledge, only a limited number of echocardiographic investigations have examined the distinctions in mitral regurgitation geometry between A-FMR and FMR associated with left ventricular dysfunction in cases with atrial fibrillation. To discover possible therapeutic targets and create suitable management techniques distinct from those utilized in Functional mitral regurgitation with left ventricular dysfunction, the precise mechanism of atrial functional mitral regurgitation must be clarified. This investigation examined the geometric distinctions in mitral valve apparatus between atrial functional mitral regurgitation and Functional mitral regurgitation with left ventricular dysfunction in cases with atrial fibrillation, utilizing three-dimensional transesophageal echocardiography.[6]

The investigation aimed to utilize three-dimensional transesophageal echocardiography (TEE) to analyze geometrical distinctions in leaflet tethering among A-FMR and V-FMR in Functional mitral regurgitation cases with atrial fibrillation.

## 2. Patients and methods

The study included 50 patients with non-valvular atrial fibrillation who had a clinical indication for echocardiography. These patients were classified into two groups based on the etiology of functional mitral regurgitation (FMR): atrial functional mitral regurgitation (A-FMR) and ventricular functional mitral regurgitation (V-FMR). This classification was defined according to the 2014 AHA/ACC guideline for the management of patients with valvular heart disease, where A-FMR is primarily caused by left atrial dilation and annular enlargement due to atrial fibrillation, while V-FMR results from left ventricular dysfunction and remodeling leading to papillary muscle displacement and leaflet tethering.

These patients visited the ECHO lab at Bab Al-Sharia Hospital, Al-Azhar University, between April 2023 and January 2025.

Inclusion Criteria:

Patients with moderate to severe functional mitral regurgitation (FMR) and persistent atrial fibrillation (AF) or atrial flutter (AFL) were included. FMR was defined as mitral regurgitation without structural abnormalities of the mitral valve (MV), such as degenerative changes, stenosis, congenital anomalies, rheumatic disease, mass, vegetation, or a history of operative or transcatheter interventions. Persistent AF or AFL was characterized by detection on an electrocardiogram at the time of transesophageal echocardiography (TOE), with a duration exceeding seven days prior to TOE.

Exclusion Criteria:

Patients were excluded if they had structural abnormalities of the mitral apparatus, severe mitral annular calcification, a history of MV annuloplasty or replacement, congenital heart disease, prior surgery for aortic valve (AV) or transcatheter AV replacement, moderate or greater AV disease, left ventricular assist devices, inadequate TOE image quality for 3D analysis, age below 18 years, or refusal to participate in the study.

Methods:

The study protocol involved obtaining signed informed consent from each patient, maintaining confidentiality through coded files, and ensuring that all investigations were used solely for scientific purposes. Ethical approval was obtained from the Faculty of Medicine, Al-Azhar University, with procedures in place to inform participants and the ethical committee of any unexpected risks.

Clinical data collection included detailed history taking and assessment of risk factors such as gender, diabetes mellitus, hypertension, hypercholesterolemia, ischemic heart disease, family history, thyroid dysfunction, smoking status, alcohol consumption, and drug addiction. Physical examinations included measurements of heart rate, diastolic and systolic blood pressure, and cardiac and chest auscultation. Resting 12-lead surface ECGs were performed for all patients, with right ventricular (RV) and posterior leads added for select cases.

Comprehensive 2D and Doppler transthoracic echocardiography (TTE) was conducted by experienced sonographers, and transesophageal echocardiography (TOE) was performed under sedation. Echocardiographic images were stored and analyzed offline by a blinded investigator in accordance with current guidelines.[7,8] Left ventricular (LV) volume and ejection fraction (LVEF) were evaluated using the modified Simpson's method[9], while left atrial (LA) volume was measured using the biplane area-length method[9] and indexed to body surface area.

The mechanisms and severity of valvular heart disease were assessed using both TTE and TOE. Mitral regurgitation severity was graded based on semiquantitative and quantitative parameters, including vena contracta width (VCW), effective regurgitant orifice area (EROA), and regurgitant volume.[7,8] Three-dimensional echocardiographic datasets were acquired using live 3D zoom or one-beat full-volume modes and analyzed offline using commercial software, including MVN and 3DQ tools in QLAB.[10]

3D Mitral Valve Geometric Analysis:

Three-dimensional transesophageal echocardiography (3D-TEE) was used to assess mitral valve geometry, utilizing commercial software (MVN and 3DQ tools in QLAB). The following 3D mitral valve (MV) indexes were measured:

Mitral annular area (cm²): Total annular surface area.

Mitral annular perimeter (cm): Circumference of the mitral annulus.

Mitral annular height-to-commissural width ratio (HCR): Measures annular flattening.

Anterior mitral leaflet (AML) area (cm²): Surface area of the anterior leaflet.

Posterior mitral leaflet (PML) area (cm²): Surface area of the posterior leaflet.

Total leaflet area (TLA, cm²): Sum of AML and PML areas.

Tenting volume (mm³): Measures the displacement of mitral leaflets toward the left ventricle.

Tenting height (mm): Vertical distance from the mitral annular plane to the coaptation point.

Posterior mitral leaflet angles (°): Central, lateral, and median angles indicating leaflet tethering.

These parameters provide a quantitative assessment of MV geometry, distinguishing A-FMR and V-FMR based on annular dilation, leaflet tethering, and coaptation changes.

## 3. Results

The mean age was comparable between the two groups, with no significant difference (A-FMR: 56.32 ± 8.9 years, V-FMR: 55.08 ± 7.23 years, p = 0.835). Similarly, gender distribution was not significantly different between groups (p = 0.327). The mean heart rate was significantly higher in the V-FMR group compared to the A-FMR group (97.2 ± 5.2 bpm vs. 80.2 ± 6.9 bpm, p < 0.05), suggesting greater hemodynamic stress in V-FMR cases (Table 1).

*Table 1. Demographic and clinical information analysis of studied cases*

| | A-FMR (MEAN±SD / N, %) | V-FMR (MEAN±SD / N, %) | P-VALUE |
|---|---|---|---|
| AGE (YEARS) | 56.32± 8.9 | 55.08 ±7.23 | 0.835 |
| GENDER (FEMALE) | 9 (45%) | 13 (43%) | 0.327 |
| GENDER (MALE) | 11 (55%) | 17 (57%) | 0.327 |
| HEART RATE (BPM) | 80.2 ± 6.9 | 97.2 ± 5.2 | <0.05 |

Concerning the MR severity study and comparison between both groups, we didn't find a significant distinction among them, as regard the degree of MR severity, p=0.819, table (2).

*Table 2. Comparison among both groups as regard MR severity*

| | | Group | | Total | p-value |
|---|---|---|---|---|---|
| | | A-FMR | V-FMR | | |
| Degree (graded severity of MR) | 2 | 7 | 8 | 15 | 0.819 |
| | | 35.0% | 26.7% | 30.0% | |
| | 3 | 7 | 12 | 19 | |
| | | 35.0% | 40.0% | 38.0% | |
| | 4 | 6 | 10 | 16 | |
| | | 30.0% | 33.3% | 32.0% | |

p-value not significant

Studying the description of MR in both groups revealed that, the mean effective MR orifice in A-FMR was 0.3±0.04 cm2, while in V-FMR was 0.37±0.044, p=0.222, the volume of regurgitation in both groups was 54.8±5.3 and 56.3±4.9 ml, respectively with p-value=0.316. The Vena Contracta width was 6.6±0.6 and 6.4±0.6 mm, correspondingly, p=0.324, table (3).

*Table 3. Comparison among both groups as regard MR description*

| | | Mean | SD | Minimum | Maximum | p-value |
|---|---|---|---|---|---|---|
| Effective Reg Orifice, $cm^2$ | A-FMR | .3600 | .04790 | .29 | .42 | .222 |
| | V-FMR | .3763 | .04422 | .28 | .45 | |
| | Total | .3698 | .04596 | .28 | .45 | |
| Regurgitant volume, ml | A-FMR | 54.8750 | 5.37018 | 45.00 | 62.00 | .316 |
| | V-FMR | 56.3723 | 4.93934 | 43.07 | 63.00 | |
| | Total | 55.7734 | 5.11572 | 43.07 | 63.00 | |
| VCW TOE, mm | A-FMR | 6.6600 | .65807 | 4.90 | 7.40 | .324 |
| | V-FMR | 6.4700 | .66288 | 5.10 | 7.50 | |
| | Total | 6.5460 | .66092 | 4.90 | 7.50 | |
| VCW 2D, mm | A-FMR | 6.4900 | .63900 | 4.50 | 7.10 | .104 |
| | V-FMR | 6.1967 | .59624 | 4.90 | 7.10 | |
| | Total | 6.3140 | .62434 | 4.50 | 7.10 | |

TOE, transesophageal echocardiography, VCW=Vena contracta width

Studying the distinction between both groups regarding TTE, LA diameter in A-FMR was 4.9±0.3 mm, while in V-FMR was 5.1±0.3, p=0.027. The LA volume index was 74.45±13.4 and 78.43±14.2 ml/m2 correspondingly, p=0.327. The Tricuspid annular plane systolic excursion (TAPSE) was 20.6±3.5 and 19.5±2.7 mm, correspondingly, p=0.219. The LV-ESV index was 54.95±13.7 and 73±20.2 ml/m2, p=0.001. A statistically significant distinction has been observed among both groups as regard EF, p=0.001, table (4).

*Table 4. Comparison among both groups as regard TTE description*

| | | Mean | SD | Min | Max | p-value |
|---|---|---|---|---|---|---|
| LA diameter, mm | A-FMR | 4.935 | .3787 | 4.5 | 5.9 | .835 |
| | V-FMR | 5.187 | .3830 | 4.6 | 6.0 | |
| | Total | 5.086 | .3974 | 4.5 | 6.0 | |
| LA volume index, mL/m2 | A-FMR | 74.45 | 13.430 | 53 | 105 | .327 |
| | V-FMR | 78.43 | 14.258 | 52 | 102 | |
| | Total | 76.84 | 13.933 | 52 | 105 | |
| TAPSE, mm | A-FMR | 20.65 | 3.558 | 16 | 26 | .219 |
| | V-FMR | 19.53 | 2.763 | 15 | 26 | |
| | Total | 19.98 | 3.120 | 15 | 26 | |
| LV-ESD, mm | A-FMR | 42.00 | 11.756 | 27 | 61 | .422 |
| | V-FMR | 131.47 | 492.197 | 25 | 2737 | |
| | Total | 95.68 | 381.302 | 25 | 2737 | |
| LV-EDD, mm | A-FMR | 50.95 | 5.375 | 41 | 61 | .647 |
| | V- | 55.33 | 5.979 | 46 | 68 | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | FMR | | | | | |
| | Total | 53.58 | 6.088 | 41 | 68 | |
| LV-ESV index, mL/m2 | A-FMR | 54.95 | 13.732 | 39 | 92 | .001* |
| | V-FMR | 73.00 | 20.230 | 47 | 108 | |
| | Total | 65.78 | 19.877 | 39 | 108 | |
| jet area ratio | A-FMR | 6.660 | .5404 | 5.7 | 7.5 | .585 |
| | V-FMR | 6.553 | .7450 | 4.8 | 7.3 | |
| | Total | 6.596 | .6667 | 4.8 | 7.5 | |
| EF % | A-FMR | 55.40 | 8.350 | 35 | 65 | .001* |
| | V-FMR | 39.37 | 7.627 | 26 | 59 | |
| | Total | 45.78 | 11.154 | 26 | 65 | |

TAPSE= Tricuspid annular plane systolic excursion, LV-ESD=LV end-systolic diameter, LV-EED=LV end-diastolic diameter, LV-ESV=LV end-systolic volume, SD= Standard deviation, *p-value is significant

A statistically insignificant distinction has been observed among both groups as regard Anterior Mitral Leaflet AML-area and posterior Mitral Leaflet PML area, p=0.388, 0.156 correspondingly, table (5).

*Table 5. Comparison among both groups as regard AML & PML*

| | | Mean | SD | Min | Max | p-value |
|---|---|---|---|---|---|---|
| AML-area | A-FMR | 746.05 | 51.604 | 670 | 870 | .388 |
| | V-FMR | 762.73 | 74.405 | 657 | 950 | |
| | Total | 756.06 | 66.161 | 657 | 950 | |
| PML-area | A-FMR | 637.35 | 40.764 | 575 | 710 | .156 |
| | V-FMR | 654.90 | 43.034 | 580 | 745 | |
| | Total | 647.88 | 42.612 | 575 | 745 | |

TLA, total leaflet area;

On the other hand, a statistically significant distinction has been observed among both groups as regard PML angles, central, lateral and median angles, as the p-value was 0.001, 0.002 and 0.001 correspondingly, table (6).

*Table 6. Comparison among both groups regarding PML angles*

| | | Mean | SD | Min | Max | p-value |
|---|---|---|---|---|---|---|
| PML-angle(central) | A-FMR | 39.05 | 4.298 | 33 | 47 | .001* |
| | V-FMR | 44.80 | 5.423 | 35 | 55 | |
| | Total | 42.50 | 5.715 | 33 | 55 | |
| PML-angle(lateral) | A-FMR | 30.30 | 4.231 | 23 | 38 | .002* |
| | V-FMR | 40.37 | 5.898 | 29 | 49 | |
| | Total | 36.34 | 7.235 | 23 | 49 | |
| PM-median angle | A-FMR | 29.50 | 4.894 | 21 | 37 | .001* |
| | V-FMR | 43.37 | 5.000 | 35 | 51 | |
| | Total | 37.82 | 8.436 | 21 | 51 | |
| coopted area mm | A-FMR | 136.250 | 10.8525 | 117.0 | 152.0 | .291 |
| | V-FMR | 139.667 | 11.2383 | 116.0 | 159.0 | |
| | Total | 138.300 | 11.1030 | 116.0 | 159.0 | |

PML, posterior mitral leaflet, *p-value is significant

A statistically significant distinction has been observed among both groups as regard MR tenting measurement, for Volume and height, as the p-value was 0.001 and 0.002 correspondingly, table (7).

*Table 7. Comparison among both groups regarding Tenting Volume and height*

| | | Mean | SD | Minimum | Maximum | p-value |
|---|---|---|---|---|---|---|
| tenting volume, mm | A-FMR | 1.595 | .4211 | .9 | 2.3 | .001* |
| | V-FMR | 3.077 | .3971 | 2.5 | 4.0 | |
| | Total | 2.484 | .8365 | .9 | 4.0 | |
| tenting height, mm | A-FMR | 4.490 | .6897 | 3.4 | 5.7 | .002* |
| | V-FMR | 7.987 | 1.0126 | 6.4 | 9.8 | |
| | Total | 6.588 | 1.9457 | 3.4 | 9.8 | |

*p-value is significant

## 4. Discussion

In our study, both groups were comparable in terms of age (A-FMR: 56.32±8.9 years vs V-FMR: 55.08±7.23 years) and gender distribution. This demographic similarity between groups strengthens the validity of the comparisons made.

These findings align with previous studies, such as the work of Kagiyama et al.[11] who reported similar age distributions in their FMR cohorts.

In our study, a significant distinction in mitral regurgitation severity was observed between atrial functional mitral regurgitation and ventricular functional mitral regurgitation groups (p=0.819). The effective regurgitant orifice area (A-FMR: 0.3±0.04 cm² vs V-FMR: 0.37±0.044 cm²), regurgitant volume (A-FMR: 54.8±5.3 ml vs V-FMR: 56.3±4.9 ml), and vena contracta width were also comparable between groups. This finding is particularly noteworthy as it suggests that despite different underlying pathophysiological mechanisms, both types of FMR can lead to similar degrees of regurgitation severity.

This agrees with Okamoto et al.,[12] who found insignificant distinctions in quantitative MR severity of regurgitant volume A-FMR and V-FMR.

In accordance with this, Uno et al.[13] investigated geometric distinctions in the MV apparatus among A-FMR and V-FMR associated with left ventricular dysfunction in cases with AF utilizing three-dimensional TOE. They stated that the VCW assessed via long-axis view on transesophageal echocardiography and the coapted area, which exhibited a correlation with vena contracta width ($r = -0.464$, $P < 0.001$), were comparable between the two groups.

A key finding in our study was the significant distinction in left ventricular ejection fraction (EF) between groups (A-FMR: 55.40±8.35% vs V-FMR: 39.37±7.62%, p=0.001). This marked distinction reflects the fundamental distinction in pathophysiology between atrial functional mitral regurgitation and ventricular functional mitral regurgitation, with ventricular functional mitral regurgitation being associated with impaired left ventricular function.

This finding is consistent with the work of Ito et al.,[5] who reported similar EF patterns in their comparative analysis.

Bai et al.[14] aimed to examine the geometric distinctions of the mitral valve among atrial fibrillation cases with and without left ventricular dysfunction. It has been revealed that LAEF decreased significantly in the AFMR and VFMR groups compared to the control group, and LAEF had a positive correlation with AAF.

In our study, studying the distinction between both groups regarding TTE, LA diameter in A-FMR was 4.9±0.3 mm, while in V-FMR was 5.1±0.3, p=0. 835. The LA volume index was 74.45±13.4 and 78.43±14.2 ml/m2 respectively, p=0.327.

According to Uno et al.[13] insignificant distinctions have been observed in left atrial size and mitral annular area between atrial functional mitral regurgitation and ventricular functional mitral regurgitation. Consequently, mitral annular dilatation is a prevalent geometric change in atrial functional mitral regurgitation and ventricular functional mitral regurgitation.

In our study, the LV-ESV index showed significant distinctions between groups (A-FMR: 54.95±13.7 ml/m² vs V-FMR: 73±20.2 ml/m², p=0.001), indicating greater ventricular remodeling in V-FMR cases.

This aligns with the established pathophysiology of V-FMR and supports findings from previous studies by Yoon et al.[15] that v-FMR showed LV remodeling.

A notable finding in our investigation was the significant distinction in posterior mitral leaflet (PML) angles between groups. All three measured angles (central, lateral, and median) showed significantly higher values in the V-FMR group (p=0.001, 0.002, and 0.001 correspondingly). This geometric distinction suggests distinct patterns of valve deformation between A-FMR and V-FMR, which could have important implications for therapeutic approaches.

These findings expand upon previous work by Uno et al.,[13] who described similar geometric patterns in their analysis of mitral valve deformation in FMR. They investigated the geometrical distinctions in mitral valve apparatus among A-FMR and V-FMR in cases with atrial fibrillation utilizing three-dimensional transesophageal echocardiography. The major findings were that the total leaflet area / annular area, indicating leaflet remodelling degree, was smaller in atrial functional mitral regurgitation than in ventricular functional mitral regurgitation. Atrial functional mitral regurgitation had less mitral leaflet tethering than ventricular functional mitral regurgitation. Leaflet coaptation degree and MR severity were similar among A-FMR and V-FMR. This result might be explained by an earlier investigation, which demonstrated that the mechanical stresses produced by mitral leaflet tethering might lead to leaflet expansion Dal-Bianco et al.,.[16] To sum it up, the leaflet relative expansion or remodelling in atrial functional mitral regurgitation was not as large as in ventricular functional mitral regurgitation because of less tethering seen in atrial functional mitral regurgitation.

Our study found significant distinctions in tenting volume (A-FMR: 1.595 mm vs V-FMR: 3.077 mm, p=0.001) and tenting height (A-FMR: 4.490 mm vs V-FMR: 7.987 mm, p=0.002) between groups. These measurements indicate more pronounced geometric distortion of the mitral apparatus in V-FMR cases, consistent with the ventricular remodeling process.

This finding supports and extends previous observations by Kim et al.,[17] who reported similar patterns of tenting parameters in their analysis of FMR mechanisms.

Uno et al.[13] reported that atrial functional mitral regurgitation had significantly smaller posterior mitral leaflet tethering height and angle measured at three anteroposterior planes (central, lateral, and medial) than ventricular functional mitral regurgitation (all $P < 0.001$).

Limitation: Our investigation had several limitations, involving its relatively small sample size, single-center design, and the lack of long-term clinical outcome data to correlate geometrical findings with patient prognosis. Additionally, the study did not evaluate mitral annular contractility, which is a key factor in functional mitral regurgitation pathophysiology. Future studies should include larger, multicenter cohorts with longitudinal follow-up to validate these findings and explore their clinical implications. Incorporating advanced imaging techniques to assess annular contractility and dynamic changes during the cardiac cycle would provide a more comprehensive understanding of the disease process.

## 4. Conclusion

The results revealed that while mitral annular dilatation and left atrial enlargement were common to both groups, there were distinct distinctions in certain parameters. Left atrial diameter was significantly larger in the V-FMR group, and significant distinctions were observed in posterior mitral leaflet angles and tenting measurements, reflecting more pronounced leaflet tethering in V-FMR. These findings underscore the shared and unique mechanisms underlying A-FMR and V-FMR, which could inform tailored therapeutic approaches.

## Disclosure

The authors have no financial interest to declare in relation to the content of this article.

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All authors have a substantial contribution to the article


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