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INVITED REVIEW

Three-dimensional assessment of the mitral valve in clinical practice

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Abstract

Three-dimensional echocardiography (3DE), via both transthoracic and transoesophageal approaches, has become an essential tool in the assessment of mitral valve (MV) disease, providing detailed anatomical and functional insights fundamental to both diagnosis and therapeutic planning. By offering a unique volumetric perspective, 3DE allows a comprehensive visualization of the entire MV apparatus, enhancing the capacity to appreciate anatomical and functional details.

In mitral regurgitation (MR), 3DE adds pivotal information about leaflet morphology, annular geometry, and sub-valvular structures across all Carpentier subtypes, playing a central role in surgical and percutaneous procedural planning. 3D colour-mode imaging improves spatial localization of regurgitant jets and enables advanced MR quantification techniques. Specifically, 3D proximal isovelocity surface area and 3D vena contracta area offer improved accuracy over 2D methods, particularly in functional MR, and in multiple or complex jets. Additionally, the 3D indirect volumetric method and emerging semi-automated software are further tools for MR quantification. In mitral stenosis, 3D planimetry via transthoracic and transoesophageal echocardiography provides more accurate and reproducible measurements of the MV area compared with 2D, especially in challenging anatomies or suboptimal imaging planes. 3DE, especially using the transoesophageal approach, also improves commissural evaluation, which is essential for patient selection for percutaneous valvuloplasty. Overall, 3DE has redefined MV imaging by offering unparalleled anatomical and quantitative assessment. Its integration into routine clinical practice is critical for modern echocardiography and should be considered a core competency for cardiovascular imaging specialists.

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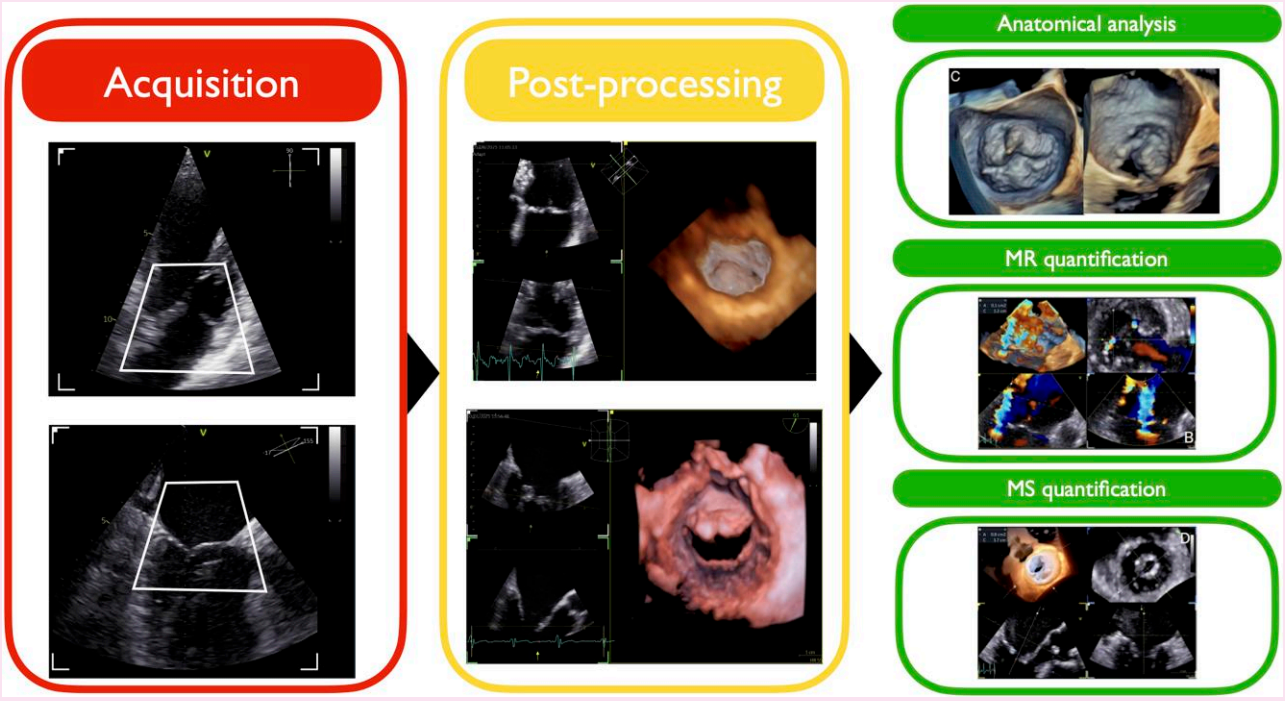
Graphical Abstract



Keywords three-dimensional echocardiography • transthoracic echocardiography • transoesophageal echocardiography • mitral valve • mitral regurgitation • mitral stenosis

Introduction

A detailed and complete assessment of mitral valve (MV), both in normal and pathological conditions, represents a daily clinical issue in every echocardiographic laboratory. The static and dynamic visualization and the evaluation of all its components (leaflets, annulus, mitral-aortic curtain, and sub-valvular apparatus) are crucial to fully understand the valvular physiopathology. This represents the fundamental basis to address an MV disease with a correct therapeutic strategy. Three-dimensional echocardiography (3DE) was first introduced in the late 1980s. Its potential for reconstructing MV anatomy with diagnostic and therapeutic implications was recognized early on.[1] Nowadays, 3DE is applied in both transthoracic echocardiography (TTE) and transoesophageal echocardiography (TEE), enabling the acquisition of the most complete dataset to describe the entire valvular apparatus. The widespread use of 3DE in MV assessment is facilitated by its favourable position within the chest in relation to the angle between the valve and the beams with both transthoracic and transoesophageal probes. Furthermore, the possibility to visualize 3D MV live images with high spatial and temporal resolution results is essential in intraoperative and interventional settings.

How to acquire a 3D TTE MV dataset

The acquisition of a 3D transthoracic MV dataset relies on obtaining optimal 2D images with sector width and depth as reduced as possible. The apical window is usually the preferred for acquiring the best 3D dataset due to physical reasons: from this view, the ultrasound beams impact the valve structures orthogonally, thus exploiting the axial resolution, the highest spatial resolution in echocardiography. To enhance the image quality, the MV should be approached as near as possible to the probe, and the '3D zoom-mode' should be utilized. Optimizing the 2D images in both orthogonal planes is crucial before acquiring the 3D dataset. The crop box should have dimensions as small as possible to enhance spatial and temporal resolutions, but large enough to include surrounding structures (e.g. the aortic valve) to allow a correct 3D orientation (*Figure 1*A). An 'over-gain' is advisable prior to storing the dataset. The acquisition can be performed in a 'single-beat' modality, in which all the volume in the crop box is acquired in one beat (*Figure 1*B). In this case, the volume rate is usually manually reduced to prioritize spatial resolution. When the frame rate is low and it is feasible (patient able to hold a breath and in a stable heart rhythm), a 'multi-beat' acquisition, in which several electrocardiogram-gated subvolumes are acquired from consecutive cardiac cycles and stitched together, allows for higher spatial–temporal resolution.

3D colour-mode acquisition requires a colour box as focused as possible on the region of interest to avoid a poor spatial and temporal resolution. In single-beat acquisition, the volume rate should be manually increased to at least 10 Hz to ensure acceptable temporal resolution, despite a decrease in spatial resolution. When possible, multi-beat acquisition is preferred to have simultaneously a good spatial–temporal resolution.

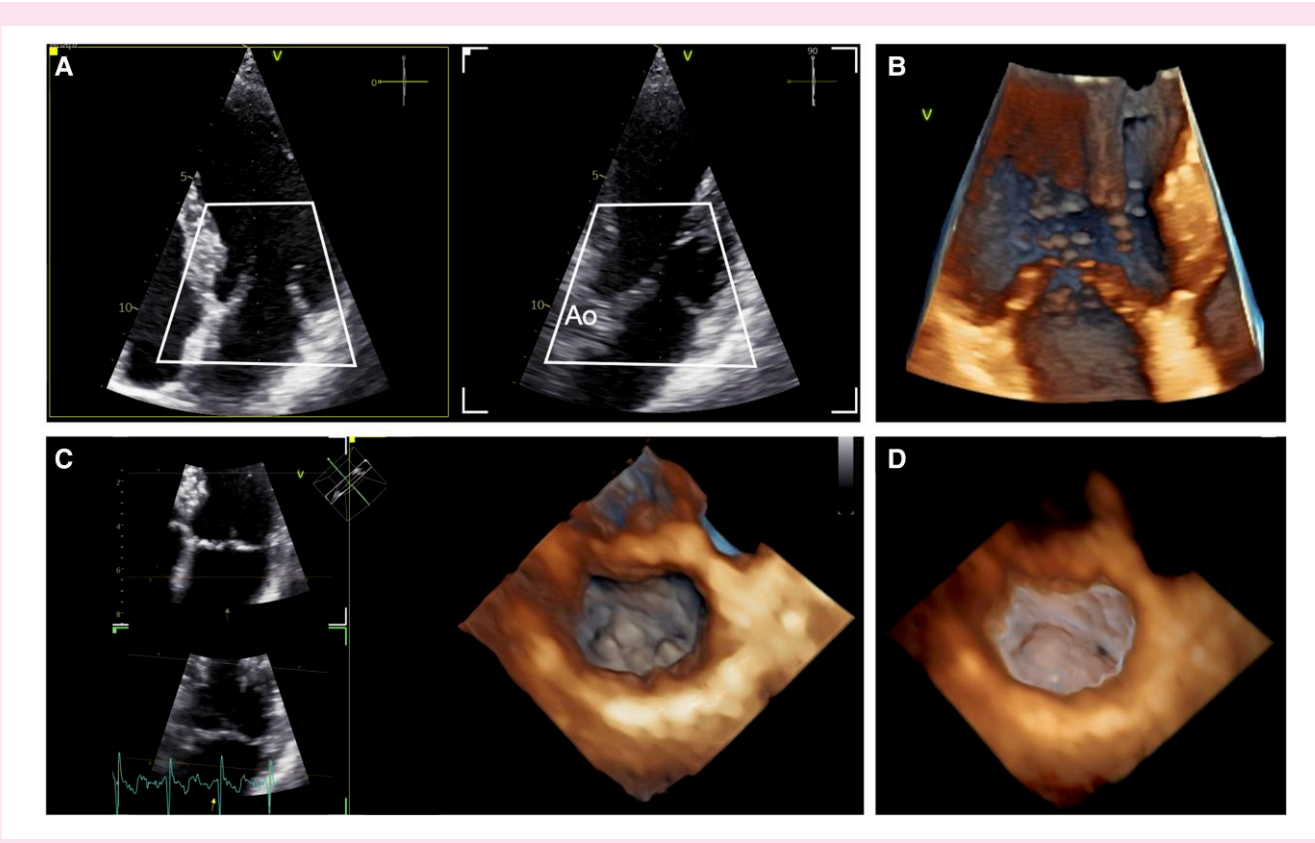


Figure 1 The correct acquisition and post-processing of a 3D TTE dataset of the MV. (*A*) Apical view with sector width and depth as reduced as possible; the '3D zoom-mode' is utilized, optimizing the 2D images in both orthogonal planes with the pyramid box as small as possible, but large enough to include surrounding structures (e.g. aortic valve). (*B*) A '3D zoom-mode' of the MV. (*C*) After cropping and rotating the image, a 'surgical view' of the MV is obtained. (*D*) A 'surgical view' with transillumination modality. Ao = aortic valve.

How to acquire a 3D TEE MV dataset

The basic principles for acquiring 3D TEE datasets are the same as those of the TTE modality. 3D TEE MV acquisition can be performed at the mid-oesophageal level in any view (typically the bicommissural), provided that high-quality 2D images are available in both orthogonal planes. The valve should be in the centre of the pyramidal volume acquisition with optimized sector width and depth, and crop box dimensions, as previously described. Modern TEE probes allow for high-quality single-beat acquisition with excellent volume rate and spatial resolution. As with TTE, 3D colour-mode acquisition follows the same principles: the colour box should be focused on the region of interest, and the volume rate should be manually increased to optimize temporal resolution. When feasible, multi-beat mode acquisition is preferred.

How to post-process a 3D MV dataset

Once the 3D dataset has been acquired, post-processing is essential to maximize 3D diagnostic accuracy and avoid potential errors (e.g. false leaflet perforation).[2] The first step involves cropping and rotating the images to create 'familiar' views for the operator. The second step is to adjust image settings, such as gain, compression, and smoothing, to optimize visualization (*Figure 1C*). Plane cutting and contextual rotation allows for focused assessment of specific lesions, such as a prolapsing scallop, or for localizing a regurgitant jet origin. Multiplanar reconstruction (MPR) can be employed to generate well-orientated 2D images and to measure anatomical orifices, such as the annulus or valvular area. Switching to the transillumination modality enables placement of a light source within the 3D space. This modality increases contrast between structures, thus highlighting a specific area of interest (*Figure 1D*).

Furthermore, semi-automated 3D analysis software allows for detailed reconstruction of MV anatomy. These tools provide precise 3D quantitative data regarding leaflet anatomy and mobility, and annular shape and size.

MV 3D echocardiographic anatomy

A deep knowledge of normal MV anatomy is essential for accurate interpretation of 3D echocardiographic images. 3D TEE is the best modality to appreciate anatomical details; thus, we will describe the anatomy through this imaging modality. Before starting, it is important to consider that, even in normal hearts, variability can interest all the MV components: leaflets morphology, number of scallops,[3] tissular annulus composition,[4] presence of annular disjunction,[5] chordae distribution, and the number and position of papillary muscles.[6]

The most familiar and applied 3D view is the atrial view, obtained with the probe in the mid-oesophageal position. It is also called 'surgical view' for the similar perspective of the valve when exposed by the surgeon (*Figure 2A*). The landmarks to correctly orientate MV in this view

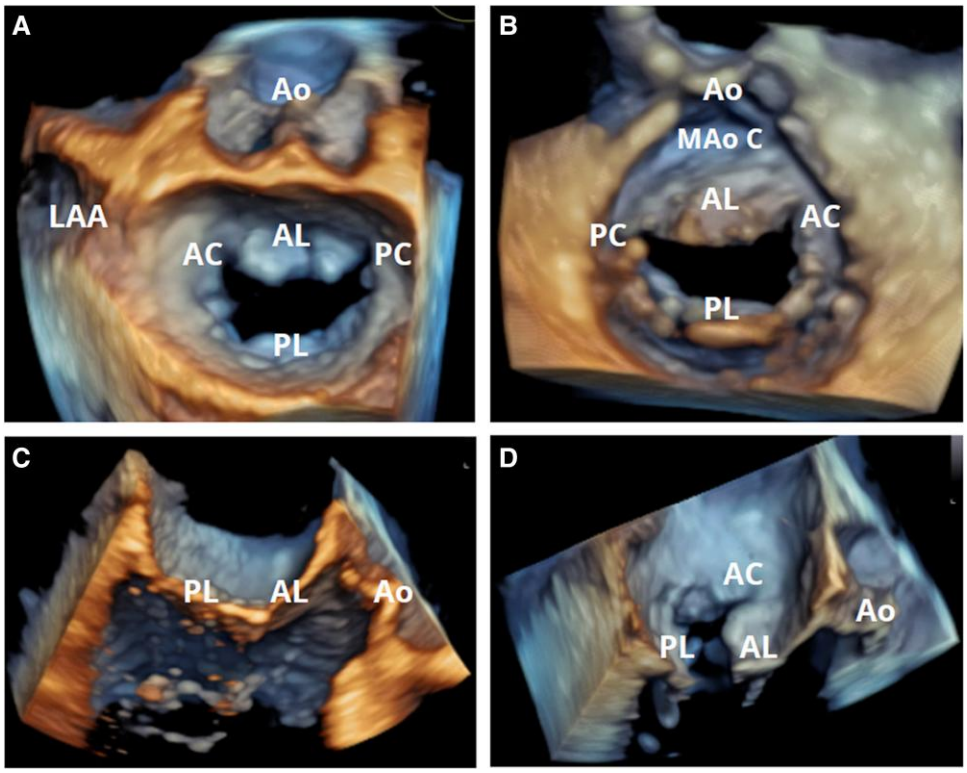


Figure 2 3D TEE MV views: (*A*) surgical view, (*B*) ventricular view, (*C*) longitudinal view, and (*D*) commissural view. AC = antero-lateral commissure, AL = anterior leaflet, Ao = aortic valve, LAA = left atrial appendage, MAo C = mitral-aortic curtain, PC = postero-medial commissure, PL = posterior leaflet.

are the aortic valve and the left atrial appendage, located respectively in the superior and lateral parts of the screen. In this view, the anterior leaflet (AL) results to be in the superior part of the screen, whereas the posterior leaflet (PL) in the inferior part. The AL, also called the 'aortic leaflet', occupies the anterior third of the annular circumference. It is anatomically separated from the non-coronary and left aortic cusps by a sheet of fibrous tissue of rectangular shape, called the mitral-aortic curtain, delimited medially and laterally by dense connective tissue, the fibrous trigones.[4,6] From the surgical echocardiographic view, it is possible to appreciate a straight AL hinge line in continuity with the atrial wall, while the mitral-aortic curtain is visualized only from the ventricular perspective. The PL, also called the 'mural leaflet', occupies the posterior two-thirds of the annular circumference. It is classically divided by indentations into three scallops: lateral (P1), central (P2), and medial (P3). Common symmetric (dominant, absent, accessory, or dichotomous P2 scallop) and asymmetric (fused or commissural scallops, accessory or dichotomous P1 or P3) variations in the PL anatomy have been described on 3D TEE.[3] The PL hinge line is C-shaped. Anatomically, a discontinuous fibrous string is often present 1–2 mm superior to the hinge line, though it is not visualizable by 3D TEE.[4] The AL length is approximately two-thirds that of the PL, while extension of the atrial surface of the leaflets is similar.[6] The coaptation line between the leaflets is arc-shaped and ends with commissures. In the surgical view, the antero-lateral commissure is on the left part of the screen, while the postero-medial is on the right.

The 'ventricular view' allows to appreciate different details (*Figure 2B*). From this perspective, the commissure orientation is contrary; thus, the antero-lateral commissure is displayed on the right and the postero-medial on the left. On the ventricular surface of both leaflets, two zones can be distinguished: a clear zone, nearer to the basal portion of the leaflet, devoid of chordal attachment, and a rough zone, nearer to the free edge of the leaflet, irregular, thicker, where the tendinous chordae attach. The indentations between the PL scallops are better visualized from this view and can be magnified through the transillumination tool, positioning the light in the left atrium. In this view, the mitral-aortic curtain can be appreciated in continuity with the left interleaflet aortic triangle, located between the left and non-coronary cusps.[4]

A third view, the 3D 'longitudinal view', includes the left ventricular cavity and allows to appreciate the chordal apparatus and papillary muscles anatomy and motion (*Figure 2C*). Most cordae arise from the apices of the papillary muscles, branch, and attach to both leaflets. Three orders of tendinous chordae are classically described according to the site of attachment to the leaflets. First-order chordae are thin, numerous, and inserted on the free edge; second-order chordae are thicker and insert on the rough zone, beyond the free edge; third-order chordae arise directly from the ventricular wall and attach only to the PL basal portion.[6]

A fourth view, the 'tangential view' or 'commissural view', offers an oblique perspective and can help in clarifying and magnifying leaflet details and characteristics, especially in assessing commissures (*Figure 2D*).

3DE applied to the valvular analysis in the mitral regurgitation spectrum

Mitral regurgitation (MR) is the condition in which 3DE finds the most widespread application in clinical practice. This is due to the high

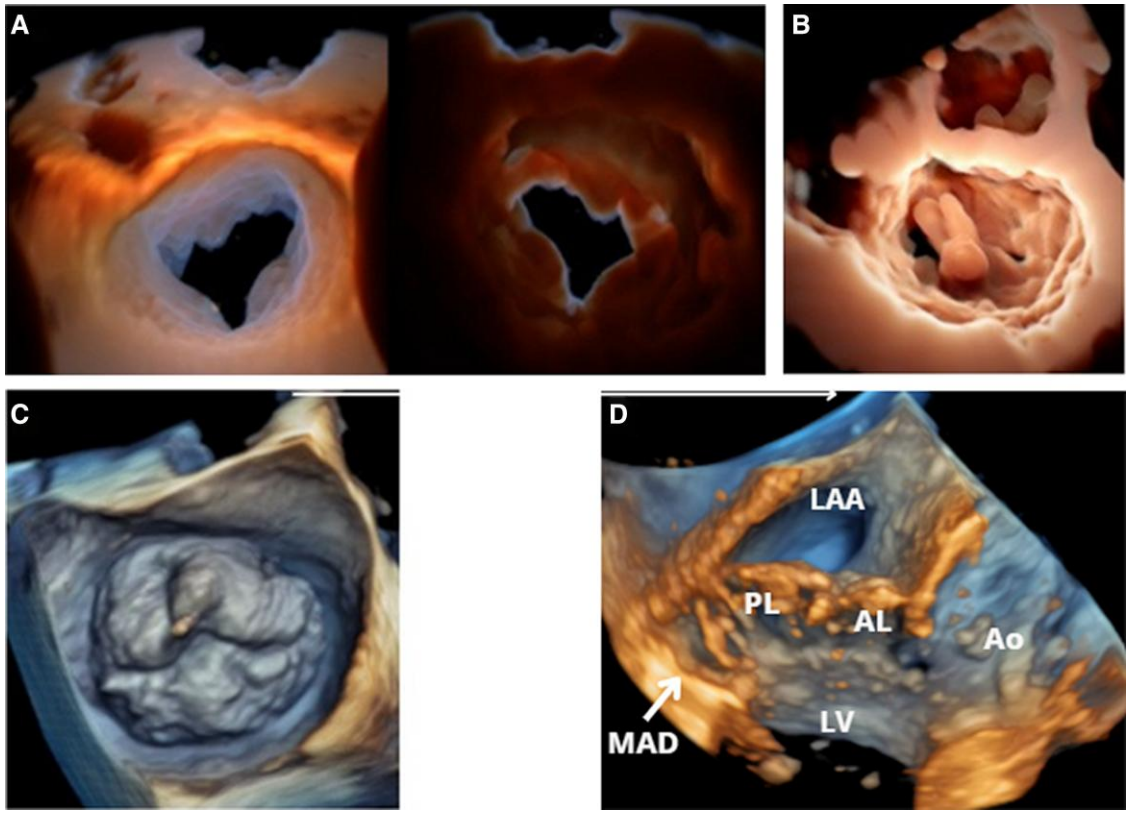


Figure 3 Type I and II MR according to the Carpentier classification. (*A*) A PL cleft seen from both surgical (on the left) and ventricular (on the right) views in a 3D TEE acquisition enhanced by transillumination. (*B*) A 3D TTE surgical view with transillumination modality showing a large P2-L flail due to multiple chordal ruptures (FED plus). (*C*) A wide bileaflet prolapse with A1 flail in a TEE surgical view of a Barlow's disease. (*D*) A TEE longitudinal view clearly showing the MAD in a Barlow's disease. AL = anterior leaflet, Ao = aortic valve, LAA = left atrial appendage, LV = left ventricle, MAD = mitral annular disjunction, PL = posterior leaflet.

prevalence of this condition,[7] and, as previously described, the favourable anatomical position of this valve relative to the probe.

MR disease is classically distinguished into primary (or organic), in which the leaflets are intrinsically affected, and secondary (or functional), in which an anatomical abnormality in the left atrium, left ventricle, or both affects the anatomy and dynamics of the MV apparatus. Alternatively, the Carpentier classification, based on leaflet motion (normal, excessive, or restricted), is still nowadays the most used in daily practice to describe MR mechanisms.

Type I MR, according to the Carpentier classification, is characterized by normal leaflets motion and includes both primary (indentations, clefts, and perforations) and secondary aetiologies.

Indentations are normally present between the scallops of the PL. When particularly deep ('cleft-like indentations'), they can result in MR. Clefts can be distinguished from the indentations because they are usually on the AL, they are deeper (usually until the hinge line of the leaflet), and they generate a significant regurgitation. Indentations and clefts may be an isolated mechanism of regurgitation or participate in the context of a prolapse or a functional regurgitation.[8] The identification of indentations and clefts represents one of the major advantages of 3DE (both 3D TTE and TEE) compared with 2D. Ventricular and surgical views in the transillumination modality are the best to identify them (*Figure 3A*). Their accurate description and localization result pivotal when planning a surgical or percutaneous MV repair (see Supplementary material). Perforations are usually the result of an infective process affecting the MV. As with the indentations and clefts, 3DE enhances their diagnostic accuracy.

Atrial functional MR, or atriogenic MR, is due to left atrial dilation, commonly associated with atrial fibrillation or left ventricular diastolic dysfunction. The relationship between leaflets length and annulus diameter, defined by the leaflet-to-annulus index (LAI, ratio between the sum of the AL and PL length over the antero-posterior diameter), is crucial in the development of regurgitation.[9] Left atrial enlargement may also displace the hinge line of PL superiorly, generating a tethering, thus reducing the coaptation between the leaflets ('atriogenic hamstringing').[10] 3D TEE depicts the normal motion of the leaflets and annular dilation. MPR and dedicated MV 3D reconstruction software using both TTE and TEE allow an accurate 3D measurement of the annulus (intercommissural and anteroposterior diameters, intertrigonal distance, perimeter, and area), which has been validated against computed tomography.[11,12] Moreover, 3DE allows a detailed analysis of MV segments in which the LAI is particularly unfavourable, identifying regions at higher risk of MR, even after an edge-to-edge repair.[13]

Type II MR in the Carpentier classification is represented by excessive leaflet motion. It includes billowing, prolapse, and flail according to the coaptation between leaflets. 3DE has a pivotal role in properly characterizing the spectrum of MV prolapse: fibroelastic deficiency (FED), fibroelastic deficiency plus (FED +), Barlow's forme fruste, and Barlow's disease (*Figure 3B–D*).[14] The 3D surgical view enables a detailed assessment of leaflet morphology, the number of PL scallops,

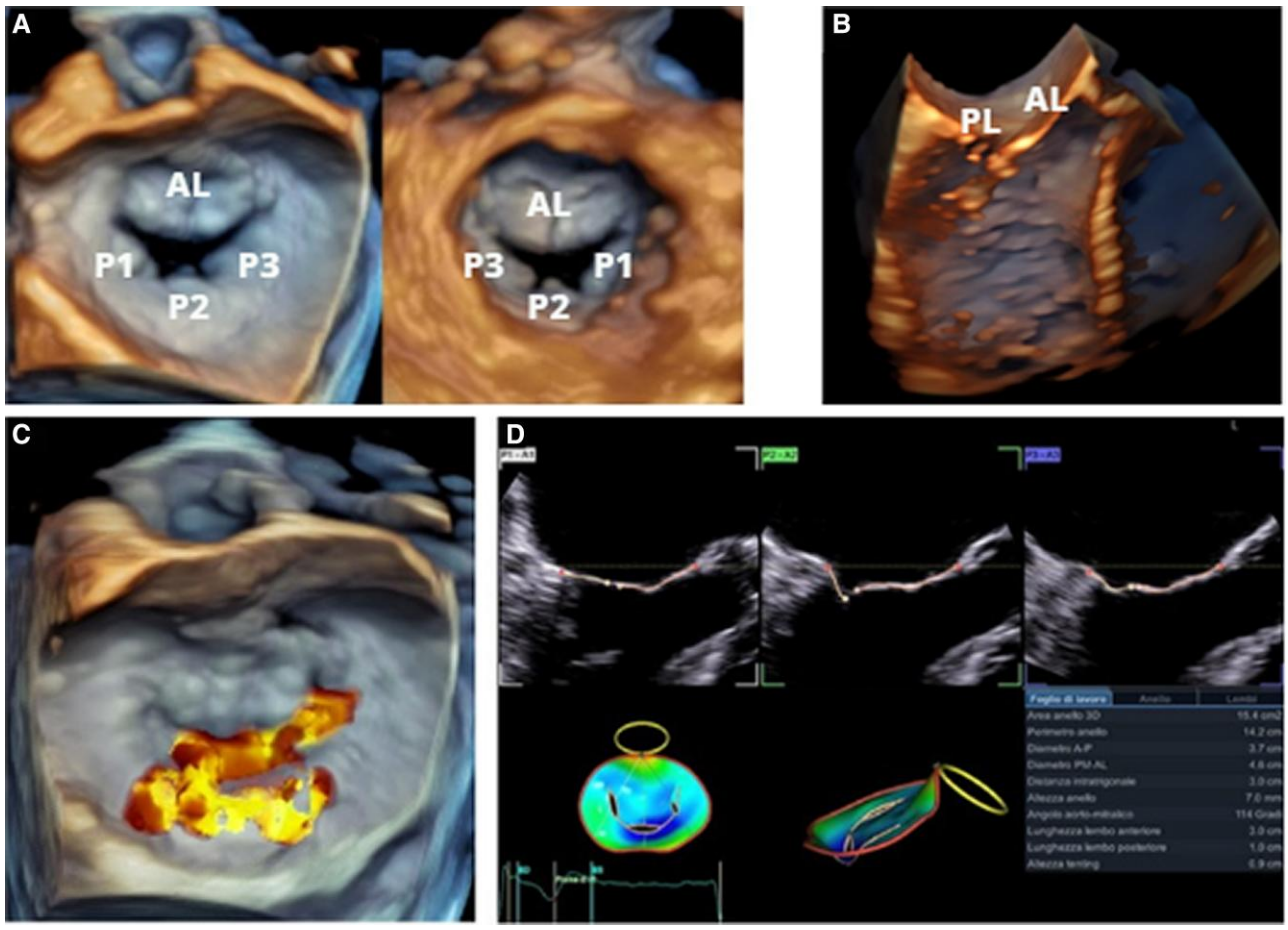


Figure 4 TEE views of a patient with Type IIIb MR according to the Carpentier classification. (*A*) PL asymmetric post-ischaemic tethering, predominant in P2–P3 scallops, seen in a 3D TEE acquisition from both surgical (on the left) and ventricular views (on the right). (*B*) 3D TEE longitudinal view with transillumination modality highlighting the displacement of the posterolateral papillary muscle, generating the tethering of the PL. (*C*) 3D TEE colour-mode surgical view showing significant MR with central-medial origin and posterior direction. (*D*) Morpho-functional 3D TEE reconstruction of the MV using a semi-automated software. 3D models of surgical and lateral views (bottom left and center) highlight in blue scallops with restricted motion due to tethering. AL = anterior leaflet, PL = posterior leaflet; lateral (P1), central (P2), and medial (P3) are the scallops of the PL.

the localization of prolapsing scallops, the shape and width of PL prolapsing segments, the presence of chordal rupture, and the annulus anatomy (e.g. the presence of calcifications). Challenging lesions, such as a commissural prolapse (due to a supplementary scallop or prolapse of the commissural region), can be accurately described via 3D TEE using a dedicated tangential view. Surgical and ventricular views in the transillumination modality are useful for assessing indentations between the leaflets (and eventually their participation in the regurgitation). MPR modality should be used to correctly localize the prolapsing scallops, measure the annulus (diameters, perimeter, area) to predict the surgical ring size,[15] and, if present, assess the mitral annular disjunction extension (*Figure 3D*).[16] A complete anatomical valvular description is pivotal in preparing for surgical MV repair. 3D TTE also provides added value over 2D, especially for localizing prolapse, identifying indentations/clefts, and quantifying the mitral annulus dimensions using MPR and/or semi-automated 3D software. The application of 3D TEE colour-mode has resulted particularly evident in characterizing MR in complex prolapse lesions, different from the classical P2 involvement. In these cases, TTE demonstrated to underestimate severe MR in non-P2 prolapse and in very eccentric jets ('horizontal' MR).[17]

Type IIIa MR describes a reduced systo-diastolic leaflet motion and includes the rheumatic and degenerative mechanisms. In this case, MR commonly coexists with mitral stenosis (MS); thus, a detailed description of these cases will be provided in the appropriate chapter.

Type IIIb MR includes the reduced systolic leaflet motion, typically due to excessive tethering of the PL (asymmetric tethering; *Figure 4A*) or both leaflets (symmetric tethering) by the sub-valvular apparatus (chordae and papillary muscles). A 3D longitudinal view is of choice to appreciate the involvement of the entire mitral apparatus in the pathogenesis of MR (*Figure 4B*). The Type IIIb mechanism is defined as 'functional' because the *primum movens* of the MR lies in left ventricular abnormality (a homogeneous dilatation or a regional myocardial dysfunction). However, fibrotic and retracted leaflets and cleft-like indentations are not uncommon in this context. Accurate 3D surgical and ventricular views allow to appreciate the leaflets morphology. Finally, 3D semi-automated TTE and TEE software can provide information about the degree of leaflets tethering (tenting height and area) and the PL postero-lateral angle, which are useful in predicting the probability of MV repair both in surgical[18] and percutaneous[19] settings (*Figure 4D*).

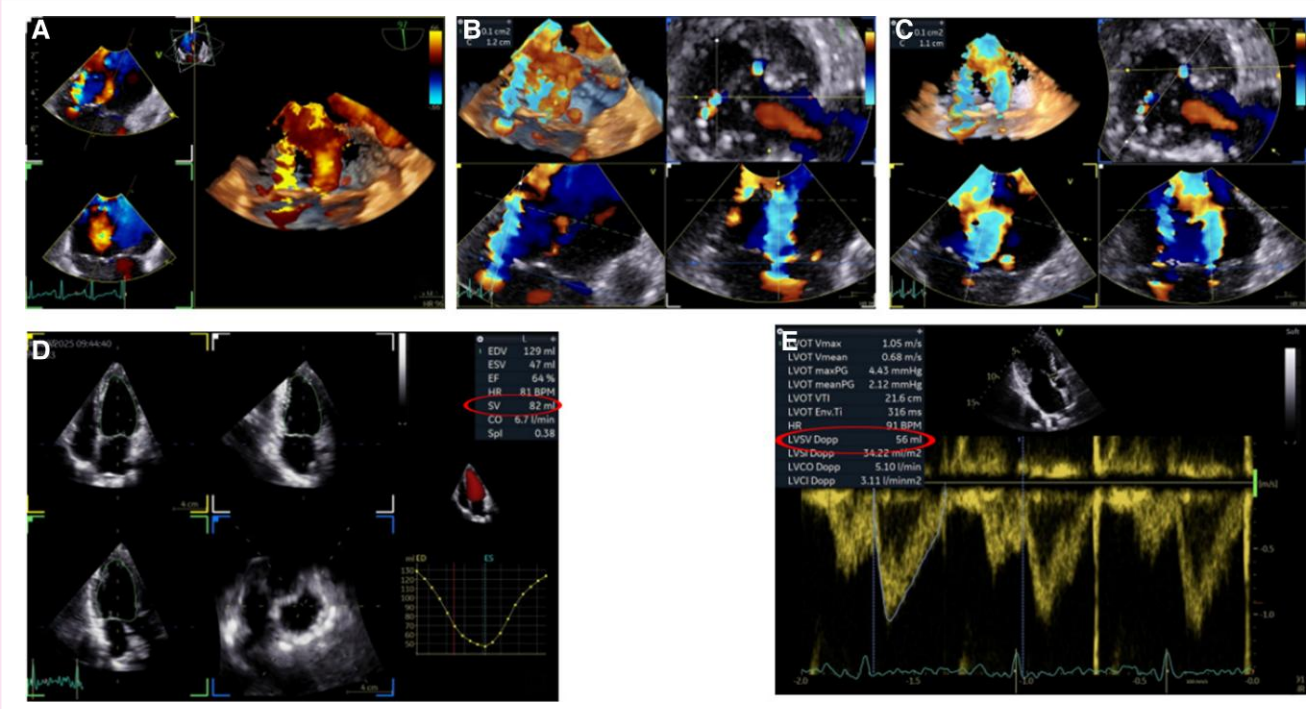


Figure 5 3D VCA and volumetric method for MR quantification. (*A*) 3D TEE cropped view showing MR in a bileaflet prolapse characterized by two predominant central–medial jets. (*B*) and (*C*) 3D VCA of the two main jets. (*D*) and (*E*) The volumetric method indirectly quantifies MR, and its results are particularly useful in the case of multiple jets: RV is calculated as the difference between total stroke volume derived from 3D LV semi-automated quantification (red circle, panel *D*) and forward stroke volume by pulsed-wave Doppler (red circle, panel *E*).

In all the MR described above, 3D colour-mode, both in surgical and ventricular views, enables precise spatial localization of regurgitant jets (*Figures 4*C and *5*A). Low-velocity blood flow (anterograde flow) can also be suppressed to clarify the acquisition and improve the retrograde flow visualization. 3D colour-mode is especially valuable in the planning of surgical or transcatheter MV repair procedures.

Type I, II, and IIIb mechanisms of MR can be treated through a transcatheter edge-to-edge approach, if clinically indicated.[19] An accurate pre-procedural and intraprocedural 3D valvular analysis, including the transillumination modality and MPR, is essential to achieve the best possible result in terms of MR reduction while avoiding the induction of a haemodynamically significant MS (see Supplementary Material).

3DE applied to MR quantification

Current recommendations propose a multiparametric approach to estimate MR degree during TTE.[20] This approach is necessary because each echocardiographic parameter has an intrinsic limitation in estimating MR severity.

2D proximal isovelocity surface area (PISA) is still nowadays the standard method to quantify the MR effective regurgitant orifice area (EROA) and regurgitant volume (RV). It assumes that blood approaches the regurgitant orifice through concentric hemispheres of isovelocity. However, in many cases—especially in functional MR, the convergence zone is elliptical, leading to an underestimation of MR severity. The 3D PISA method was introduced in 2011 and has the advantage of measuring the surface of the convergence zone of isovelocity without geometric assumptions.[21] In all degrees of MR, RV measured by phase-contrast cardiac magnetic resonance (CMR) demonstrated better agreement with RV obtained using 3D PISA than with 2D PISA.[22] The difference in MR volume between 3D PISA and 2D PISA resulted significant (>15 mL) in the subgroup of patients with severe MR and/or eccentric jets and/or with an asymmetric orifice.[22] Furthermore, in a meta-analysis including 2D and 3D PISA and volumetric methods, RV derived by the 3D PISA method showed the best agreement with CMR, underestimating RV on average by 3.20 mL.[23] Limitations in the use of 3D PISA method are the use of a single frame to measure the convergence area (which can overestimate EROA and RV), the misalignment between the ultrasound beam and MR jet (Doppler angle effect), and the cases of multiple jets, where EROA and RV are not summable.[24,25] All these cited restrictions have progressively limited the use of 3D PISA method in the daily clinical practice.

To overcome the PISA method's intrinsic limitations, 3D vena contracta area (VCA) has been introduced[26] and validated in multiple cohorts of patients across different degrees of MR severity. The principle of 3D VCA is to directly measure the 3D colour planimetry using MPR (*Figure 5*B and C). It can be applied using both TTE and TEE, provided that adequate temporal resolution is achieved (at least 10–12 Hz). The first applications of 3D VCA for MR quantification were provided by TTE in patients with at least mild MR.[27] A cutoff of 0.41 cm^2 was identified as the optimal cutoff to distinguish between moderate and severe MR.[27] Importantly, the 2D EROA PISA method demonstrated to underestimate MR by 27% compared with 3D VCA in the case of functional MR.[27] Further data derived from TEE confirmed that 3D VCA was comparable to 2D PISA in the case of single jet, but superior in the case of multiple jets, where 3D VCA allows for summation of the single cross-sectional areas.[28] Goebel *et al.* validated a specific 3D TEE VCA cutoff for MR severity according to MR mechanism: 0.41 cm^2 for primary MR and 0.39 cm^2 for secondary MR.[29] 3D VCA

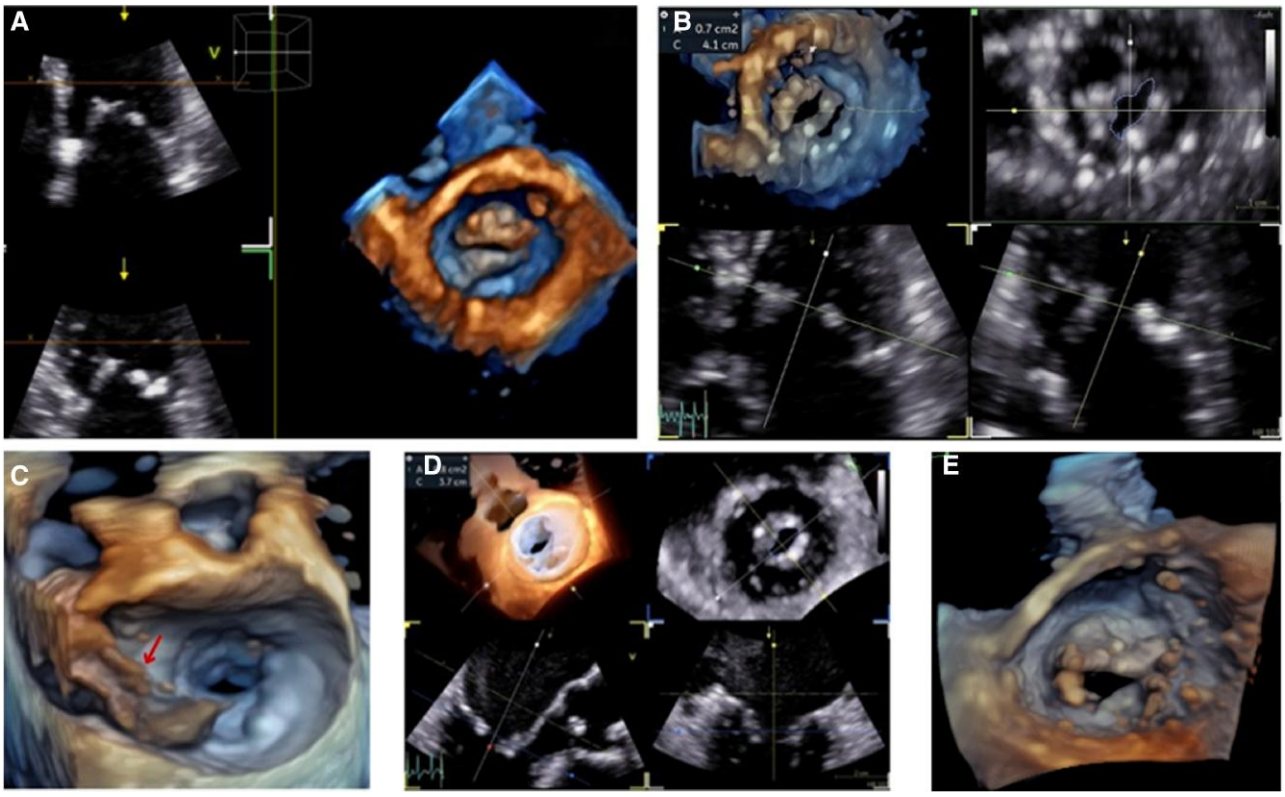


Figure 6 3D TEE and TEE assessment of MS. (*A*) 3D TTE ventricular view of a rheumatic MS. (*B*) MVA by 3D TTE planimetry. (*C*) 3D TEE surgical view of the same case, enhancing a severe 'smoke effect' from LAA (red arrow). (*D*) MVA by 3D-TEE planimetry (reproducible with TTE result). (*E*) 3D ventricular view of another case of rheumatic MS showing bicommissural fusion and chordal thickening.

alone was superior to the 2D PISA method for grading MR, especially in the case of functional MR.[29] Recently, 3D VCA values were retrospectively analysed in patients with MV prolapse and at least moderate MR undergoing TEE.[30] A 3D VCA cutoff of 0.45 cm^2 accurately distinguished moderate from severe MR (assessed by a multiparametric reference method), and 3D VCA showed larger values than EROA estimated by the 2D PISA method.[30] This aspect was particularly evident in the case of advanced degenerative myxomatous degeneration, in which multiple and non-circular regurgitant orifice areas were often found.[30] Despite its advantages, 3D VCA also has limitations: an acceptable spatial–temporal resolution may not be achievable, selecting a systolic frame to measure the 3D planimetry can cause interobserver variability, and the MPR process can be challenging in eccentric jets and can require a time commitment and expertise.[31]

The 3D volumetric method allows indirectly to measure RV and EROA. RV is calculated as the difference between the left ventricular total stroke volume (end-diastolic–end-systolic volume) and the forward stroke volume (derived from 2D Doppler echocardiography) (*Figure 5D* and *E*). EROA is then obtained by dividing RV by the velocity-time integral of the MR jet measured by the continuous-wave Doppler.

This method is particularly useful in functional MR and in cases with eccentric and/or multiple jets. RV and EROA derived through this method have improved the risk stratification in patients with ventricular functional MR compared with 2D volumetric and PISA methods.[32]

A novel semi-automated 3D MR quantification technique using 3D colour-mode TEE has been recently proposed to quantify the RV.[33,34] It is based on a fluid dynamics model described by the simplified Navier–Stokes equations, enabling 3D analysis of flow convergence proximal to the surface of the regurgitant orifice without relying on geometric assumptions. RV derived via this 3D semi-automated quantification has shown better correlation with CMR than RV measured by 2D PISA TTE and TEE, and may be particularly useful in the case of complex MR with multiple and eccentric jets.[33] However, its use in clinical practice is limited by the need to have a frame rate ranging from 20 to 40 Hz in 3D colour-mode.

3DE applied to MS

According to current European guidelines, the evaluation of MS severity should be primarily based on the anatomical measurement of the MV area (MVA) by the 2D planimetry.[19] Alternative methods (pressure-half time, continuity equation, and PISA) as well as hemodynamic parameters (mean transvalvular gradients and estimated pulmonary pressures) should be used to complement and integrate the assessment.[35] 2D planimetry is performed in the parasternal view, short-axis view at the tip of the leaflets when a minimal excursion of the leaflet is observed. The accurateness of this measurement is affected by the angle between the 'true' MVA (the minimal measurable area in mid-diastole) and the ultrasound beam.[36] This angle resulted significant (≥9.5°) in cases of left atrial dilation.[36] 3D TTE planimetry demonstrated a good reproducibility and a better agreement with invasive MVA than 2D measures.[37,38] A 3D 'zoom-mode' acquisition with a multi-beat modality (in case of patient in sinus rhythm) is advisable to have a good temporal resolution not missing the frame in which MV is at its maximum opening (*Figure 6A*).[39] MPR modality allows to

individuate and to be well aligned with the tip of MV leaflets, thereby eliminating the overestimation of 2D planimetry (*Figure 6B*).

3D TEE planimetry has shown lower MVA values compared with 2D planimetry and demonstrated an excellent reproducibility as well (*Figure 6C* and *D*).[36,40] All 3D TEE views, particularly the tangential view, allow for a detailed assessment of commissural anatomy (partial or complete fusion, degree of calcification) (*Figure 6E*).[40] This aspect is mandatory when a percutaneous mitral balloon valvuloplasty is planned. Anwar *et al.* proposed a 3D TEE-based scoring system evaluating both leaflets (anatomy and mobility) and sub-valvular apparatus to help select patients suitable for percutaneous valvuloplasty.[41]

Conclusions

3DE represents an essential tool in any echocardiographic laboratory when MV disease is evaluated from diagnostic and therapeutic perspectives. The ability of acquiring and editing 3D TTE and TEE datasets, analysing physiological and pathological valvular images in 3D, and exploiting 3D to quantify MR and MS should be considered a core competence of the modern echocardiographer.

Supplementary data

Supplementary data are available at *European Heart Journal - Imaging Methods and Practice* online.

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Data availability

No new data were generated or analysed in support of this research.

Lead author biography

Prof. Patrizio Lancellotti, MD, PhD, is the Head of the Cardiology Department at the University of Liège Hospital, CHU Sart Tilman, Liège, Belgium. The Cardiology Department consists of a large group of renowned cardiologists, and several consultants, trainees, and fellows. The Department's facilities include modern technologies, latest cardiovascular imaging machines, several cath labs, and hybrid rooms. Prof. Lancellotti is an expert in Cardiovascular Imaging, Valvular Heart Disease, and Interventional Structural Heart Disease. He is Past-President of the European Association of Cardiovascular Imaging, Past-President of the Belgian Society of Cardiology, and Past-Chairman of the European Society of Cardiology Council on Valvular Heart Disease. Prof. Lancellotti has been involved in several journal editorial boards (*European Heart Journal*, *European Heart Journal of Cardiovascular Imaging*, *European Heart Journal—Imaging Methods and Practice*. Prof. Lancellotti has authored or co-authored over 800 publications and presented more than 280 abstracts on innovative research. He has served as Editor/co-Editor of several major books on Cardiac-Oncology, Echocardiography, Multi-imaging Modality, and Management of Valvular Heart Diseases.

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