Artigo de Revisão

Avaliação Ecocardiográfica Tridimensional do Mecanismo e da Graduação da Regurgitação Mitral

Three-dimensional Echocardiographic Evaluation of the Mechanism and Severity of Mitral Regurgitation

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RESUMO

A ecocardiografia tridimensional é uma modalidade de imagem adequada para avaliar a anatomia complexa da valva mitral assim como para determinar o mecanismo e também para graduar a regurgitação mitral. A ecocardiografia tridimensional pode ser realizada a partir da abordagem transtorácica como também transesofágica. Este artigo discute as formas de aquisição de dados e de manipulação de imagens com a ecocardiografia tridimensional. É feita também revisão de literatura em relação as aplicações clínicas da ecocardiografia tridimensional para a avaliação da valva mitral.

Descritores: Ecocardiografia Tridimensional; Insuficiência da Valva Mitral; Prolapso da Valva Mitral.

SUMMARY

Three dimensional echocardiography (3DE) is well suited to evaluate the complex anatomy of the mitral valve as well as the mechanism and severity of mitral regurgitation. 3DE can be performed both from the transthoracic as well as the transesophageal approaches. This paper will first discuss the modes of 3DE data acquisition and image manipulation followed by a review of the contemporary literature pertaining to the clinical applications of this technique for the evaluation of the mitral valve.

Descriptors: Echocardiography; Three-Dimensional; Mitral Valve Insufficiency; Mitral Valve Prolapse.

Introduction

Three-dimensional echocardiography (3DE) is well suited for studying the mitral valve (MV) due to the complex nature of its annulus, leaflets and subvalvular apparatus. Since Levine and colleagues used 3DE to demonstrate the relationship of the saddle-shaped MV annulus to the valve leaflets, the MV has been the center of 3DE research¹⁴. Advancements in 3DE have seen the evolution of the technology from image reconstruction to simultaneous biplane and volumetric imaging. Current real-time 3D (RT3D) transducers have better resolution and use matrix arrays with more than 3000 elements. In the past decade, commercially available units using similar but enhanced matrix array technology have been incorporated in standard echocardiography systems (Philips, Inc (Andover, MA), GE Healthcare (Waukesha, WI), Toshiba Medical Systems Corp (Tustin, CA), Siemens Medical Solutions (Mountainview, CA)) for transthoracic imaging. In 2007, the real time 3D transesophago-
geal (TEE) mini-matrix array probe was introduced (Philips Medical Systems, Andover, MA) which has the ability to create exquisite “true to life” images of the MV and other cardiac structures.

In a RT3D acquisition, the ultrasound beam is emitted from the transducer in the shape of a pyramid. The pyramidal volume of data is displayed on the ultrasound system. Then this volumetric data set can be sliced in any plane to display tomographic views of the heart. Depending on the manufacturer, the 3D data set can be acquired either in the “zoom” or “full volume” modes. The latter mode requires multiple beats for visualization of a full data set in most echo systems. Three-dimensional echo is an ideal tool to evaluate mitral regurgitation (MR) because it can provide detailed views of the mitral valve and MR in any plane. This paper will be a contemporary review of the 3D echo assessment of MV anatomy as well as the mechanism and severity of MR.

Assessment of Mitral Valve Anatomy: 3D Image Acquisition and Data Manipulation

The first step in the comprehensive evaluation of MR is to define its anatomy and the mechanism of regurgitation. Carpentier classified the three most common causes of regurgitation: Type 1 (dilated annulus or perforated leaflet); Type 2 (prolapsing or myxomatous leaflet); Type 3 (restricted leaflet)⁵. The second step is to quantify the severity of the regurgitation by color flow and Doppler methods which typically include the jet to atrial area ratio, vena contracta (VC), and proximal iso-velocity surface area (PISA)⁶.

The addition of 3DE to standard two-dimensional (2D) techniques has enhanced the understanding of MV anatomy. The MV can be seen in both the parasternal and apical views acquired by real-time 3D transthoracic echo (RT3DTTE) and by real-time 3D transesophageal echo (RT3DTEE) using the zoom or full volume modes. The data set can then be sliced in any plane to allow visualization of the MV from the atrial or ventricular side. This approach is critical prior to or during mitral valve surgery. Pre-operatively or in the operating room, RT3DTEE is ideal for image acquisition and data manipulation. Figure 1 demonstrates the stepwise approach used to display the MV anatomy using RT3DTEE in the zoom mode. The advantage of the zoom mode is that the acquisition requires only 1 beat and is independent of the underlying heart rhythm.

A similar approach using RT3DTEE is used to display images of the MV acquired in a full vol-
Clinical Applications of 3D Echo for Evaluation of Mitral Valve Anatomy

Identification of prolapsing MV scallops is the most useful and commonly utilized application of both RT3DTTE and RT3DTEE. An evolving volumetric technique for the identification of prolapsing scallops with RT3DTTE is called “multiplanar reconstruction (MPR)” or the “slice mode technique” (Figure 4)8,9. However, the most commonly used approach to evaluate MV anatomy is by cropping the volume rendered 3D data sets. A study by Sugeng et al. demonstrated adequate visualization of the anterior mitral leaflet (84% of patients) and posterior mitral leaflet (77% of patients) with RT3DTTE. The anterior leaflet was best seen from its ventricular perspective from either the apical or parasternal windows while both posterior leaflet surfaces were better seen from the parasternal view10. Other stud-
Several studies have compared the identification of the prolapsing scallop using RT3DTTE to surgical findings in patients with myxomatous mitral valve disease and severe mitral regurgitation. They report 95.1% sensitivity, 87.4% specificity, 97.7% negative predictive value and 76.3% positive predictive value with RT3DTTE\textsuperscript{11,12}. The incremental diagnostic value of RT3DTTE compared to 2D TTE for the identification of the prolapsing scallop has also been noted. The combination of RT3DTTE and 2D TTE has also been shown to have similar diagnostic accuracy to 2D TEE\textsuperscript{13-16}. However, flail lesions were better visualized with 2D TEE in comparison to RT3DTTE\textsuperscript{15}, emphasizing that image quality may not always be optimal for small structures using the 3D transthoracic technique.

Several studies have demonstrated the feasibility and accuracy of the first-generation 3D TEE for diagnosing MV prolapse and flail scallops when compared to surgical findings\textsuperscript{17-23}. The incremental value of 3D TEE compared to 2D TEE was found to be in commissural lesions\textsuperscript{24}. Real-time 3D TTE and first generation 3D TEE were compared to 2D methodologies in a prospective study that revealed that 3D TEE had superior accuracy when compared to RT3DTTE, 2D TEE, and 2D TTE\textsuperscript{25}. Three-dimensional TEE demonstrated a more accurate identification of all mitral valve lesions (95.6% accuracy). RT3DTTE and 2D TEE had similar accuracies (90% and 87%, respectively), while the accuracy of 2D TTE (77%) was lower when compared to surgical findings. Although such studies resulted in enthusiasm for the first generation 3D TEE systems, the cumbersome reconstruction required to generate an image limited its widespread utility.

The advent of RT3DTEE technology has sparked enthusiasm for the potential to display the mitral valve as more true to the surgical anatomy (Figure 5). Due to the posterior location of the mitral valve, TEE is an ideal modality to accurately visualize this structure. Real-time 3D TEE technology has been able to overcome the image quality limitations of RT3DTTE and the reconstruction limitations of

\textbf{Figure 4:} The “Multiplanar Reconstruction” or “Slice Mode” technique involves acquisition of a pyramidal full-volume data set from either the apical or parasternal windows. In comparison to the volume rendered images, in this technique, the 3D data set is cropped automatically to display simultaneous 2D cuts of the MV. Three orthogonal planes (panel A) are placed in a step-wise fashion to display the MV in the apical 4-chamber view (panel B), commissure to commissure view (panel C) and short axis view (panel D). The data set is divided into three orthogonal planes representing two long axis planes (panels B and C) and one short axis plane (panel D). The short axis plane is placed parallel to the mitral annulus at the level of the MV leaflets. Then the two longitudinal planes are placed perpendicular to one another in a long axis configuration. One plane extends along the line formed by the two commissures. The other longitudinal plane is oriented 90° from the commissure to commissure plane. The MV is then sliced from the anterolateral to the posteromedial commissure using the short axis plane as a reference. As the MV is sliced in the short axis plane, the corresponding MV anatomy is also visualized in the two longitudinal planes simultaneously to determine the location of the prolapsing scallop. In this example, panel B shows a prolapsing P2 scallop (arrow). The P2 location is confirmed by noting the central location of the cut planes in panels C and D.

\textbf{Figure 5:} Images of a Barlow’s mitral valve. The RT3DTEE image is shown in panel A. The surgical image of the same valve is noted in panel B. Note the multiple billowing scallops typical for a Barlow’s valve.
first generation 3D TEE. Sugeng and colleagues published the first study evaluating the accuracy of the mini-matrix array RT3DTEE probe (Philips Medical Systems, Andover, MA) in 211 patients. They demonstrated excellent visualization of the MV (85% to 91% for all scallops of both MV leaflets), inter-atrial septum (84%), left atrial appendage (86%), and the left ventricle (77%). The aortic and tricuspid valves were not well visualized, 18% and 11% respectively. Grewal and colleagues prospectively examined the feasibility of RT3DTEE for patients undergoing MV repair for mitral regurgitation. Two-dimensional TEE and RT3DTEE were compared to the surgical findings. The RT3DTEE was superior to 2D TEE in diagnosis of bileaflet, P1/P3 and A2/A3 scallops. Interobserver variability for diagnosing the mechanism of MR for RT3DTEE was very good (Kappa = 0.70). Another study has shown the potential of RT3DTEE in accurately diagnosing flail lesions. Quantitative parameters achievable from the RT3DTEE data may enable us to better understand the anatomic changes associated with myxomatous valve disease and may assist with surgical planning. Real-time 3D TEE has also been useful in the evaluation of endocarditis (Figure 6) and prosthetic valve dysfunction (Figure 7).

Three-dimensional echo has also been used in the evaluation of functional MR secondary to ischemic or dilated cardiomyopathy (DCM). The geometric differences in the asymmetric deformation of the mitral annulus in ischemic cardiomyopathy (ICM) and the symmetric shape of the annulus in DCM have been shown by 3DE. Papillary muscle position in 3D space was also defined as asymmetric in ICM and symmetric in DCM. The mechanism for the development of significant ischemic MR is also caused by prominent left ventricular dilation and geometric change. Three-dimensional quan-
tification of MV tenting can show the dramatic ‘mountain-like’ deformation of the valve leaflets in ischemic-MR (Figure 8). Differences in leaflet tenting by 3DE were also observed between anterior and inferior myocardial infarctions. The MV leaflets were more widely tethered in patients with anterior infarctions. Mitral valve tent area in both ICM and DCM has been found to be one of the strongest determinates of MR severity.

Quantification of Mitral Regurgitation Severity

The second step in evaluating MR is to assess the severity by color flow and Doppler quantification. Two-dimensional assessment of MR severity is limited because direct visualization of the full regurgitant jet is not possible. This has lead to many geometric assumptions about the jet characteristics. Often several different 2D measurements are needed to comprehensively evaluate MR severity. Traditional 2D methods of MR quantification include jet area to LA ratio, VC, and PISA. Three-dimensional color Doppler overcomes these limitations by allowing direct and multi-plane visualization of the regurgitant jet.

Sugeng and colleagues compared 3DE color flow to conventional 2D color flow and Doppler methods to assess MR. When 3D MR jet/LA volume ratio was compared to 2D MR jet/LA area, the 3D volume ratio was significantly smaller. Vena contracta maximum and minimum diameters by 3DE differed significantly when compared to similar 2D VC measurements. Manually traced 3D MR volumes demonstrated good agreement with PISA-derived volumes.

Vena contracta width, the narrowest portion of the MR jet, has been used to estimate MR severity. Three-dimensional VC cross-sectional area (VCA) is essentially the effective regurgitant orifice area (EROA). Direct planimetry of the VCA by 3DE has shown that the VCA is asymmetric in patients with functional MR. Three-dimensional VCA is feasible and more accurate than 2D-VC diameter for estimation of MR severity and demonstrates a better relation to EROA (Figure 9). An in vitro study demonstrated that VCA was the strongest correlation with known orifice area ($r = 0.92$, $p <0.001$). Three-dimensional VCA was particularly useful in patients with eccentric and moderate-severe or severe MR because there was no assumption of the shape of the regurgitant orifice. The regurgitant orifice in such cases is often asymmetric, resulting in erroneous quantification of MR severity by 2D methods. A good correlation was also shown by direct planimetry of the orifice area by 3D TEE from either the left atrial or ventricular perspectives with PISA-derived EROA. The 3D geometry of PISA has also been shown to differ by MR etiology (Figure 10).
tients with ICM and DCM, the PISA is elongated as opposed to patients with MV prolapse where the PISA is rounder. This is thought to explain the underestimation of MR severity by 2D PISA methods in patients with functional MR.

Color flow imaging by RT3DTEE is in its infancy. A color flow acquisition by RT3DTEE requires seven consecutive cardiac cycles which make this technique prone to stitch artifacts. The imaging sector is also quite narrow. Therefore, it is difficult to encompass the entire mitral annulus in a single sector. Low frame rates may also result in inaccurate assessment of regurgitant jet characteristics. However, color flow imaging by RT3DTEE is very useful to define the location of valvular or perivalvular leaks (Figure 11).

**Figure 11:** RT3DTEE color Doppler is ideally suited for identification of the location of regurgitant lesions following mitral valve surgery. In Panel A, mitral regurgitation is demonstrated using 2D TEE color Doppler imaging. Panel B demonstrates the corresponding RT3DTEE color Doppler image. Note that the location of the valvular MR post-mitral valve repair is at the base of the P3 scallop, near the Annuloplasty ring (arrow). Although there is significant stitch artifact in the RT3D color image, the origin of the MR adjacent to the postero medial commissure is appreciated.

**Conclusions**

Three-dimensional echocardiography has lead to great advancements in the evaluation of the mechanism and severity of MR. Real-time 3D echo allows for the acquisition of a pyramidal data-set which can be processed to display the mitral valve which is more true to its complex anatomy. The clinical utility of 3DE has primarily been in diagnosis and surgical planning of patients with myxomatous MV disease. More research is needed with RT3DTEE in patients with functional MR. Real-time 3D TEE color flow technology is also in the early stages. Currently, there is little data on color flow evaluation of MR with RT3DTEE. Further research in these areas will continue to broaden the clinical applicability of 3D technology in the assessment of mitral regurgitation.

**Referências**


