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Quantification of mitral valve stenosis by three-dimensional transesophageal echocardiography

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Abstract

The aim of this study was the evaluation of the diagnostic potentials of transesophageal 3D- echocardiography in the determination of mitral valve stenosis. 54 patients were investigated by transthoracic and multiplane transesophageal echocardiography. In 41 patients cardiac catheterization was performed. 3D- echocardiographic data acquisition was performed by automatic transducer rotation at 2° increments over a span of 180°. The transesophageal probe was linked to an ultrasound unit and to a 3D-workstation capable of ECG- and respiration gated data acquisition, postprocessing and 2D/ 3D image reconstruction. The mitral valve was visualized in sequential cross-sectional planes out of the 3D data set. The spatial position of the planes was indicated in a reference image. In the cross-sectional plane with the narrowest part of the leaflets the orifice area was measured by planimetry. For topographic information a 3D view down from the top of the left atrium was reconstructed. Measurements were compared to conventional transthoracic planimetry, to Doppler-echocardiographic pressure half time and to invasive data. The mean difference to transthoracic planimetry, pressure half time and to invasive measurements were 0.3 ± 0.1 cm^2, 0.2 ± 0.1 cm^2 and 0.1 ± 0.1 cm^2, respectively. Remarkable differences between the 3D- echocardiographic and the 2D- or Doppler- echocardiographic methods were observed in patients with severe calcification or aortic regurgitation. In 22% of the patients the 3D data set was not of diagnostic quality. New diagnostic information from a 3D view of the mitral valve could be obtained in 69% of the patients. Thus, although image quality is limited, 3D- echocardiography provides new topographic information in mitral valve stenosis. It allows the use of a new quantitative method, by which image plane positioning errors and flow-dependent calculation is avoided.

Introduction

Echocardiography and Doppler-echocardiography have evolved to the most common used diagnostic methods in mitral valve disease. The techniques are non-invasive, safe, comparatively inexpensive and allow serial assessment of mitral valve stenosis. Determination of the mitral orifice area is performed by planimetry in the parasternal short axis or by flow dependent calculation using the pressure-half-time method or the continuity equation. Heart catheterization is regarded as the clinical golden standard in the quantification of mitral valve stenosis but is limited on the other hand by its invasive nature. However, remarkable differences between echocardiographic and invasive measurements have been reported. [1–3] Most recently dynamic three-dimensional echocardiography has been introduced, providing images from which new quantitative methods in mitral valve disease can be derived. [4–11] The purpose of this study was the evaluation of the accuracy of three-dimensional transesophageal echocardiography for determination of mitral valve stenosis in comparison to transthoracic echocardiographic two-dimensional planimetry and Doppler-echocardiography.

Methods

The study group consisted of 54 patients (32 men, 22 women, mean age 59 [35–79]) with mitral valve stenosis. All patients underwent transthoracic and multiplane transesophageal echocardiography. 10 patients revealed concomitant moderate or severe aortic regurgitation in the echocardiographic investigations and in cardiac catheterization. In 41 patients cardiac catheterization was performed. Heart catheterization and transesophageal echocardiographic examinations were performed after written informed consent.

Echocardiographic transthoracic examinations were performed with commercially available ultrasound units (Hewlett Packard Sonos 1500, Vingmed CFM 800). For echocardiographic transesophageal examinations 5 MHz multiplane transducers (Vingmed, Hewlett Packard) were used. The three-dimensional imaging system consisted of the multiplane transesophageal probe linked to the ultrasound unit and to a 3D-workstation (Tomtec) capable of ECG- and respiration gated data acquisition, postprocessing, interpolation and two- or three- dimensional image reconstruction in shaded surface techniques. Data acquisition was performed during the conventional multiplane transesophageal echocardiographic investigation using rotational scanning. Two-dimensional tomographic planes were acquired by automatic transducer rotation at 2° increments over a span of 180°. Three-dimensional data acquisition was standardized. The transducer was positioned in the esophagus in a way, that the mitral valve was scanned in the 4-chamber view at 0° and in the 2-chamber view at 90°. Postprocessing and image reconstruction were performed off-line.

In all patients the mitral valve orifice area was determined by planimetry in conventional transthoracic two-dimensional and in an individually optimized cross-sectional plane in three-dimensional transesophageal echocardiography as well as by transesophageal continuous Doppler-echocardiography using the pressure half-time. In two-dimensional transthoracic echocardiography planimetry of the inner border of the narrowest mitral valve orifice was performed in a parasternal short-axis view. Pressure half-time was depicted from continuous wave Doppler tracings of transmitral flow in transesophageal four chamber views. Measurements were performed manually averaging five beats in sinus rhythm or seven beats in atrial fibrillation. The mitral valve orifice area was then calculated as reported by Hatle et al. [12]. Beats with an diastolic filling period shorter than 300ms were excluded for technical reasons. The severity of aortic regurgitation was judged based on the ratio of the cross sections of the regurgitant color jet and the left ventricular outflow tract, as previously described [13]. In patients who were referred to the catheter laboratory the mitral orifice area was determined using the Gorlin formula from cardiac output and the transmitral pressure gradient. [14,15] Time between echocardiographic and invasive determination of the mitral orifice area was within 6 days.

In three-dimensional transesophageal echocardiography the mitral orifice area was determined in the so-called paraplane or anyplane mode. Here the mitral valve was visualized simultaneously in 4 to 9 parallel and equidistant or non-parallel, cross-sectional planes out of the three-dimensional data set in stop frames or cineloop. (Figure 1) The spatial position of each cross-section is indicated by bars in a reference image. The reference image contents a conventional transesophageal longitudinal view of the mitral valve. The cross-section of the narrowest part of the mitral valve is found by operator defined cranial or caudal movement of those bars and slight modification of the perspective of the cross-sectional planes. The narrowest part of the valve represents the stenotic valve area and was quantified by planimetry. For topographic information a three-dimensional view from the top of the left atrium down on the mitral valve was reconstructed.

Statistical analysis

Linear regression analysis was performed on the data to compare Doppler-echocardiography and cineventriculography with three- dimensional and two-dimensional echocardiographic planimetry. The mean difference and its standard deviation between the measured orifice areas was calculated as a function of increasing orifice area. Intra- and interobserver variability was calculated as the standard deviation of the differences between measurements of one and two observers, respectively. It was expressed as a percent of the average value.

Results

The three-dimensional echocardiographic measurements based on transesophageal multiplane echocardiography were possible in 78% (42/54) of the patients. In 22% (12/54) of the patients the three- dimensional data set was not of diagnostic quality due to artifacts and a loss of sharpness leading to border detection

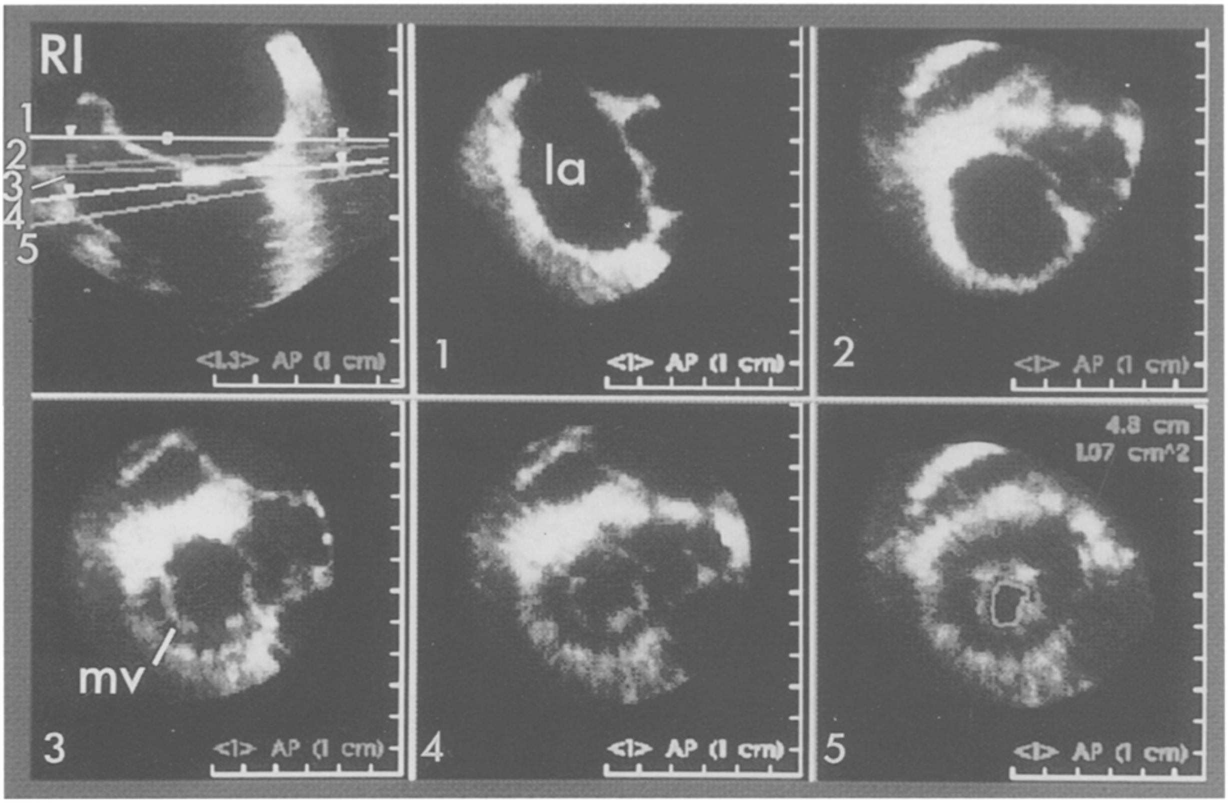

Figure 1. Three-dimensional anyplane mode with sequential cross-sectional views of a stenotic mitral valve. The reference image in the upper edge represents a transesophageal longitudinal view of the mitral valve. The position of each cross-section is indicated by numbered bars in the reference image. The number of a bar in the reference image corresponds to the cross-sectional planes through the mitral valve. The bar No. 5 is positioned at the most distal and narrowest part of the mitral leaflets. The according tomographic plane is visualized in the right corner of the lower images, where a planimetry of the orifice area (1.07cm^2) is performed. (RI = reference image; la = left atrium; mv = mitral valve).

problems. This reduced image quality was derived from image acquisition and postprocessing, and was not correlated to the degree of mitral leaflet calcification. Figure 2 demonstrates the good agreement between three-dimensional and invasive measurements of the stenotic orifice area. There is no trend towards systematic over- or underestimation. The difference between the two methods was low and remained nearly constant with increasing orifice areas. The comparison of transthoracic two- dimensional echocardiographic planimetry and invasive measurements revealed the regression equation: y= 0.87x + 0.23 (r=0.80; SEE= 0.26 cm^2) with a mean difference of 0.2 $\pm$ 0.2 cm^2.

In figure 3 three-dimensional echocardiographic measurements were compared to two-dimensional, transthoracic planimetry. Remarkable differences were observed in single patients with severe calcification and eccentric orifices. Figure 4 illustrates the comparison between three-dimensional planimetric and pressure half-time measurements of the mitral orifice area. It demonstrates a trend towards overestimation by the pressure half-time method in patients with a moderate or severe aortic regurgitation. When transthoracic two-dimensional echocardiographic planimetry and pressure half-time were compared the following regression equation was obtained: y= 0.79x + 0.24 (r= 0.79; SEE= 0.25cm^2). Mean difference between the methods was 0.2 $\pm$ 0.2 cm^2.

Inter- and intraobserver variabilities for three-dimensional echocardiographic mitral orifice determination were 8.3% and 5.4%, respectively. In contrary transthoracic two-dimensional echocardiographic planimetry revealed 15.4% and 7.9%, respectively. Values for pressure-half time were 8.1% and 5.1%, respectively, which is similar to three-dimensional echocardiography.

In 37/54 (69%) patients a high quality three-dimensional view of the mitral valve from the top of

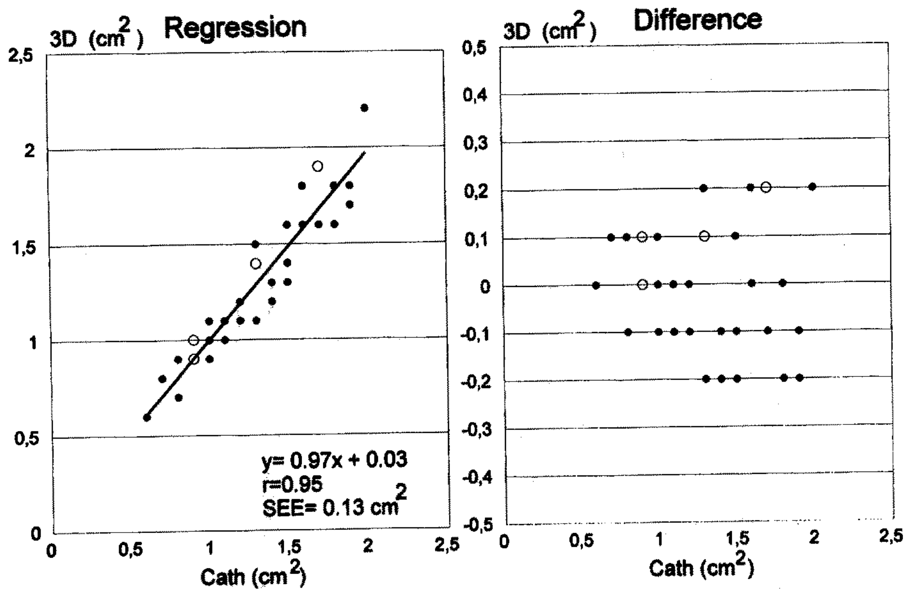

Figure 2. Comparison of three-dimensional, transesophageal echocardiographic and invasive determination of the stenotic mitral valve orifice area. On the left side the regression curve and on the right side the differences between the methods. n = 34. Mean difference = 0.1 ± 0.1cm^2. (Cath = heart catheterization; 3D = three-dimensional echocardiographic planimetry; ° = two patients with the same data).

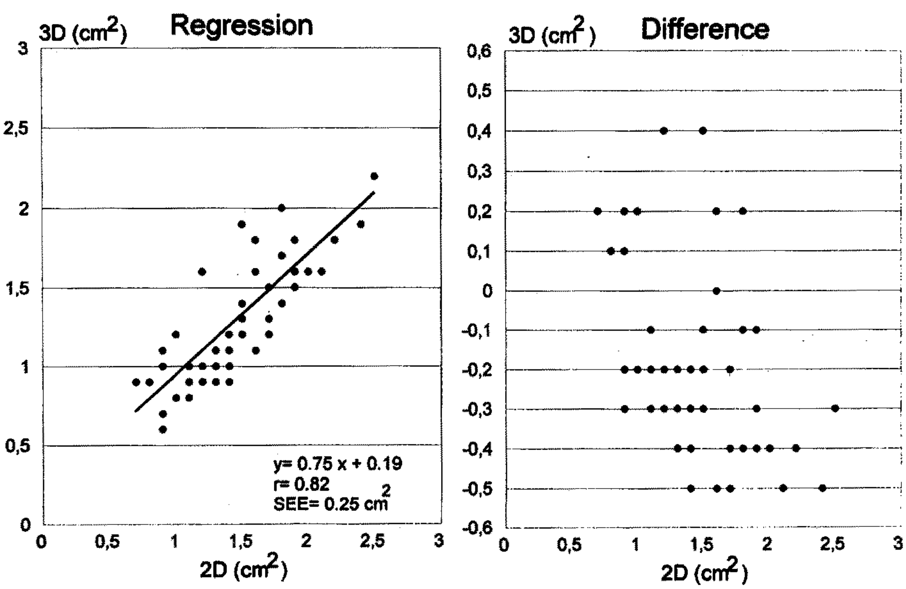

Figure 3. Comparison of three-dimensional, transesophageal and transthoracic, two-dimensional echocardiographic determination of the stenotic mitral valve orifice area. n = 42. Mean difference = 0.3 ± 0.1 cm^2. In all of the patients with a difference of 0.5 cm^2 and in 3 of the patients with a difference of 0.4 cm^2 a severe calcification with an eccentric orifice of the mitral valve was observed. (2D = transthoracic, two-dimensional planimetry in the parasternal short axis view).

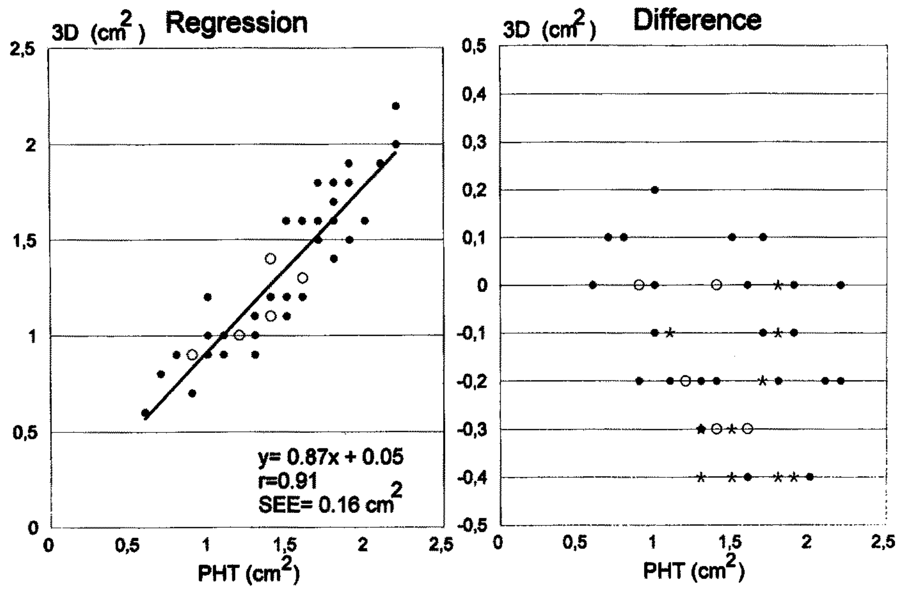

Figure 4. Comparison of three-dimensional, transesophageal echocardiographic and the pressure half-time method in the quantitation of stenotic mitral orifice area. Although the mean difference was 0.2 ± $0.2cm^2$, remarkable overestimation by the pressure half-time method occurred in single patients; preferably in those with a moderate or severe aortic regurgitation. n = 42. (PHT = pressure half- time; ★ = patients with a moderate or severe aortic regurgitation).

the left atrium could be obtained providing topographic information, which could not be achieved by two-dimensional transesophageal echocardiography. Figure 5 illustrates a mitral valve after balloon valvuloplasty with a new, moderate eccentric regurgitation originating from the anterior part of the mitral ring. In two-dimensional multiplane transesophageal echocardiography no differentiation between a rupture of a leaflet or the mitral ring was possible. The three-dimensional image demonstrates a discontinuity in the anterior part of the mitral ring, suggesting a rupture of the mitral ring. The patient underwent surgery, and intraoperative findings confirmed three-dimensional echocardiography.

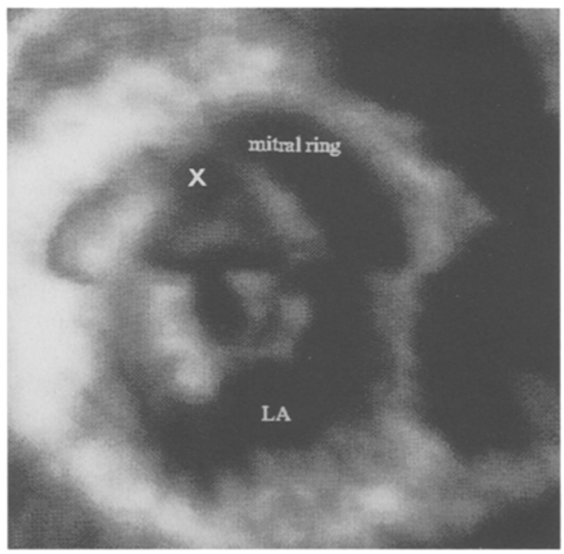

Figure 5. Three-dimensional echocardiographic, transesophageal image of the mitral valve ring after balloon valvuloplasty in a view from the top of the left atrium. In multiplane transesophageal echocardiography a moderate, eccentric regurgitation was detected. The discontinuity at the anterior part of the mitral ring (x) represents a partial tear of the ring.

Discussion

Two-dimensional transthoracic and Doppler-echocardiography are excellent methods to determine the stenotic mitral valve orifice area. However, in single patients image positioning errors or flow-dependent calculation lead to remarkable measurement errors. The three- dimensional data set does not only allow three-dimensional topographic visualization of cardiac structures but also two-dimensional imaging in a defined perspective. The spatial localization of any two-dimensional plane can be controlled objectively.

The position of a specific plane in conventional two-dimensional echocardiography is orientated dependent on anatomic landmarks and on the experience of the operator.

Good correlation was described between transthoracic two-dimensional planimetry and invasive or intraoperative measurements of the mitral orifice area.(16–19) The significance of the method is limited in patients with reduced quality of images or severe calcification of the leaflets.(20) In transesophageal echocardiography planimetry of the mitral valve orifice area can only be performed in the transgastral view, which can not be achieved regularly. In two-dimensional images no parameter exists to assure that the cross-section of the narrowest part of the valve orifice is visualized precisely. Tangential imaging and overestimation of the valve orifice can not be excluded, as shown in our study. Three-dimensional echocardiography has partly overcome this problem by visualizing the complete mitral valve in sequential cross-sectional planes and simultaneous indication of those planes in a longitudinal view. By this way image plane positioning errors are avoided, leading to the precise visualization of the narrowest part even of eccentric and calcified valve orifices. However, the operator might be influenced by two-dimensional transesophageal echocardiography, where the orifice is visualized by color flow Doppler imaging. The results of this study suggest, that the elimination of image plane positioning errors lead to more accurate reproducibility and to a more precise correlation to invasive measurements, when compared to two-dimensional transthoracic planimetry.

The pressure-half-time method is widely accepted for determining the orifice area by means of Doppler techniques. [21–23] Values provide a helpful approach in the assessment of the severity of mitral valve stenosis, but remarkable variability occurs with transvalvular volumetric flow, limiting the significance of pressure gradients as the only parameter in the quantification of mitral valve stenosis. [24, 25] Remarkable discrepancies between the pressure half-time method and invasive measurements were described, when an aortic regurgitation is present. [1–3, 24] That might be caused by an rapid increase in left ventricular pressure, leading to a shortening of the pressure half-time and consequently to an overestimation of the orifice area. Results of this study show the advantage of the three-dimensional planimetric determination of the orifice area, which is independent of flow characteristics.

Multiplane transesophageal echocardiography is an excellent method to image the mitral valve in different tomographic views. [26] On the other hand the technique delivers only two-dimensional views of a three- dimensional reality. Three-dimensional echocardiography delivers images as the view on the mitral valve from the top of the left atrium, which can not be obtained from two-dimensional echocardiography. [27, 28] Those images are very similar to the surgical view during operation. Thus, surgeons might get an preoperative impression of the pathologic morphology of the mitral valve, which is of major influence in choosing the surgical technique, since there is still a lack of objective parameters in the indication of a valve repair [29, 30].

Limited image quality led to not-diagnostic three-dimensional echocardiographic investigations in a part of the patients. Image quality is reduced by artifacts and minor resolution, which is due to the shading surface techniques. Furthermore additional investigation time is required. The conventional echocardiographic techniques could be utilized in all patients, which underlines their unique importance. On the other hand three-dimensional echocardiographic planimetry provides increased reproducibility and more precise measurements in patients with aortic regurgitation and eccentric orifices, in whom conventional measurement techniques revealed a lack of accuracy. Nowadays significant mitral valve stenosis is regarded as an indication for multiplane transesophageal echocardiography, to assess whether percutaneous mitral balloon valvuloplasty or surgery is indicated. Therefore transesophageal three-dimensional echocardiography can be performed easily without additional disturbance of the patient.

Conclusion

Three-dimensional echocardiography is a new tool in cardiac imaging techniques. In mitral valve stenosis it offers an additional quantitative method which can not be performed by conventional two-dimensional transthoracic or transesophageal echocardiography. Although image quality is still limited, the planimetry of the mitral orifice area can now be performed with high accuracy, reproducibility and without image positioning errors in a major part of patients. The three-dimensional views from different perspectives offer new topographic information with important diagnostic and therapeutic implication.

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