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Pre-operative transthoracic real-time three-dimensional echocardiography for a better surgical strategy

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Rezumat

Ecocardiografia transtoracică tridimensională în timp real preoperatorie pentru o strategie optimă operatorie

În acest studiu s-a urmărit rolul ecocardiografiei transtoracice (ETT) tridimensionale (3D) în evaluarea morfologiei valvelor cardiace, la pacienți cu valvulopatii.
Metodă: Un număr de 104 pacienți consecutivi, propuși pentru intervenție chirurgicală valvulară au fost investigați ETT bidimensional (2D) și 3D în timp real, și prin cateterism cardiac. Utilizând datele intraoperatorii ca standard de aur, s-au comparat rezultatele ETT 2D cu cele 3D, privind morfologia valvulară. S-a folosit un scor de apreciere al segmentelor valvulare (0=incorect, 1=corect).
Rezultate: Ecocardiografia 3D a oferit o vizualizare corectă a segmentelor valvulare comparativ cu ETT 2D, la mai mulți pacienți (731/770 ETT 3D versus 693/770 ETT 2D, $p<0.01$). Segmentele cuspelor au fost identificate mai bine ETT 3D decât 2D (502/531 versus 471/531, $p<0.01$). Evaluarea comisurilor a fost asemănătoare prin cele două metode ecocardiografice (229/239 versus 222/239, $p=0.09$). Sorul total ETT 3D pentru valvele mitrală și aortică a fost semnificativ mai bun decât scorul total ETT 2D (media scorului 12.91±1.62 3D versus 11.58±1.02 2D, $p=0.02$). Superioritatea ETT 3D a fost demonstrată indiferent de ritmul cardiac ($p<0.05$ în ritm sinusal și în fibrilație atrială). Sensibilitatea și specificitatea ETT 3D a fost de 91% și 84%, iar pentru ETT 2D de 85% și 77%.
Concluzii: Ecocardiografia 3D în timp real este superioară ETT 2D în ce privește localizarea și depistarea patologiei valvulare, indiferent de ritmul cardiac.

Cuvinte cheie: ecocardiografie transtoracică tridimensională, în timp real, chirurgie valvulară cardiacă, ecocardiografie preoperatorie

Abstract

In this study we aimed to evaluate the three-dimensional (3D) transthoracic echocardiography (TTE) in the assessment of cardiac valve morphology.
Methods: Bidimensional (2D) and real-time 3D TTE was performed in 104 patients consecutive with cardiac catheterisation, prior to valve surgery. Using surgical findings as the gold standard, 2D and 3D TTE were compared for adequate recognition and accurate detection of morphology. A scoring protocol was used for recognition of the valvular segments (0=inadequate, 1=adequate).
Results: Adequate echographic visualization of the valve segments was more frequently obtained by 3D than 2D TTE imaging (731/770 by 3D TTE vs. 693/770 by 2D TTE, $p<0.01$). The valve leaflets segments were more clearly identified by 3D TTE rather than by 2D TTE (502/531 vs. 471/531, $p<0.01$). The assessment of commissures was similar by both methods (229/239 vs. 222/239, $p=0.09$). Total 3D TTE scores

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for mitral and aortic valves were significantly better than 2D TTE scores (mean score 12.91±1.62 by 3D vs 11.58±1.02 by 2D, p=0.02). This superiority of 3D TTE was irrespective of rhythm ($p<0.05$ for both sinus rhythm and atrial fibrillation). Using surgical classification of valvular disease as gold standard, the sensibility and specificity were 91% and 84 % for 3D TTE, and 85% and 77% for 2D TTE, respectively.
Conclusions: Real-time 3D was superior to 2D TTE for the accurate localization and identification of valvular pathology, irrespective of heart rhythm.

Key words: transthoracic real-time three dimensional echocardiography, cardiac valve surgery, preoperative echocardiography

Introduction

Bidimensional (2D) transthoracic echocardiography (TTE) plays a vital role in the assessment of cardiac valve morphology. If diagnosis is no more a problem, the precise location and the extent of the valvular anomaly is still difficult to assess using 2D TTE. However, the accuracy of this method may be limited by inadequate recognition of all segments. Several studies have underlined the importance of early surgical intervention, particularly valve repair, to preserve long term left ventricular function in significant valvular diseases (1,2). As repair techniques have advanced, so has the need to obtain accurate information prior to surgery. Some studies suggest that adding three-dimensional (3D) imaging to standard 2D TTE could be helpful in the quantification of valvular diseases.

Three-dimensional echocardiography is a new emerging technique that allows recording of volumetric echographic data (3). This technique can provide views of the entire valve, allowing a complete assessment of the valve leaflets and commissures (4-14). Real-time 3D TTE has a good accuracy (14-17), so that several authors recommended already to integrate this new technique in the standard preoperative examination and become an important tool in the decision to process valvular repair/replacement.

The aim of this prospective study was to evaluate three aspects of real-time 3D TTE: (i) the accuracy of the method (vs. surgical inspection) in patients undergoing surgery for valvular disease; (ii) to compare the accuracy of 3D TTE with 2D TTE; (iii) to compare the valvular area measured 3D TTE and 2D TTE with the area determined by Gorlin method, in patients with significant valvular stenosis.

Material and Method

Patient population

One hundred and twenty-six consecutive patients with aortic and/or mitral valvular disease referred to surgery were evaluated by 2D and 3D TTE. Exclusion criteria were represented by inadequate echocardiografic images, movement artifacts caused by coughing or hiccough, difficulty with ECG registering, and equipment failure.

Study protocol

A complet transthoracic echocardiographic study (2D and 3D) was obtained prior to or following the invasive study, in a time gap <12 h; surgery was done in the next 7 days. Three-dimensional and 2D TTE data were compared with invasive and, then with surgical data. The local ethics committee approved the study. Informed consent was obtained from all patients.

Transthoracic 2D and 3D echocardiography

The TTE study was performed in all patients using Sonos 7500 or IE33 ultrasound units with S3 and, respectively S5-1 sector array probes (Philips Medical Systems, Andover, MA, USA). Two-dimensional TTE views of the mitral and aortic valves were obtained from the parasternal window; the planimetry was also performed. Three cardiac cycles for patients in sinus rhythm and five for patients in atrial fibrillation were recorded, and their results averaged for every patient.

Real-time 3D TTE was performed at the end of the 2D examination with the same ultrasound units by utilizing an X4 or an X3-1 probes. The protocol included real-time parasternal views with zoom technology that allowed a more focused image of the entire mitral or aortic valve. "Full volume" analysis was also performed in all cases from the apical view. Image processing was done off-line using the QLAB software (Philips Medical Systems, Andover, MA, USA). Real-time 3D TTE planimetry was performed "en-face" at the ideal cross-section of the mitral and aortic valve, during its greatest opening (13,15). The ideal cross-section was defined as the most perpendicular view on the plane with the smallest mitral/aortic valve orifice.

The Carpentier nomenclature was applied to the mitral leaflets (18). Each scallop of posterior leaflet was defined through the indentations (or clefts when present) which anatomically divided the valve in lateral (P1), central (P2), and medial (P3) segments. The anterior leaflet scallops facing the posterior ones were classified as A1, A2, and A3. The antero-lateral (ALC) and postero-medial (PMC) commissures were also evaluated.

All valvular segments were classified as normal, prolapsing (displacement of any part of leaflet above the annular plane due to chordal elongation), flail (eversion of leaflet tip into left atrium during systole due to chordal rupture), tenting (malcoaptation due to left ventricular dysfunction and sub-valvular traction), perforation (breech of leaflet body), erosion (leaflet edge destruction), fibrosis or calcification. The fusion of the commissures, vegetations, ruptured chordae and bicuspidy were also noted. Gross etiology was classified as degenerative, congenital, infective, or functional. Three-dimensional acquisition and reconstruction times were measured in each patient.

A single echocardiographer acquired and measured the 2D and 3D echo studies. Calculations were averaged from three cycles (five non-extreme cycles in case of atrial fibrillation).

Invasive evaluation

Invasive hemodynamic evaluation was performed within 12 h of the echocardiographic recordings. Using the catheter-based data and the Gorlin's equation, the mitral and/or aortic valve area was obtained (19,20).

Surgical inspection and validation

The surgeon described the anatomy of the aortic and mitral valve. He was aware of the 2D findings, but not of the 3D analysis. All valvular segments were classified as normal, prolapsing, flail, tenting, perforation, erosion, fibrosis or calcification. For the mitral valve the Carpentier classification was used. The fusion of the commissures, vegetations, ruptured chordae, and bicuspidy were noted.

Scoring protocol

The 2D and 3D TTE images were analysed off-line separately and blinded to the surgical findings. Segments considered inadequate were not included for the analysis. Valvular morphology data described by the operating surgeon was used as gold standard. He described the anatomy of the valve using the same proforma like for echocardiographic analysis. The surgeon was aware of the 2D findings but not of the 3D analysis. Segments were counted as accurately imaged if they matched surgical findings precisely in terms of pathology description and correct location (score = 1). The segments that were not adequately recognised (score = 0) were coded as inaccurate. For segments that were adequately recognised, the reasons for inaccuracies were recorded as incorrect description of pathology (e.g. calling a "prolapsed" segment "flail") or incorrect localisation despite correct identification of the pathology.

Statistical analysis

The sensitivity and specificity of the echocardiographic evaluation were calculated with surgical data as a reference. Variables are expressed as proportions, mean, and standard deviation. The chi-squared test and the student t-test with subsequent two-tailed t-tests were used to compare differences between groups. Correlation and agreement between planimetry measured by 2D and 3D TTE and invasive area were evaluated by Bland–Altman plots. Differences were considered statistically significant at the two-sided $P < 0.05$ level. All computations were carried out with the software SPSS 17.0 for Windows (SPSS Inc. Chicago, IL, USA).

Results

From 126 screened patients between January 2008 and December 2009, 104 (43 womans) were enrolled in the study. Average age was 52±14 years. Characteristics of the patients study group are presented in Table 1. For each patient, 1-3 acquisitions were realized and the best one chosen for imaging and quantification. Acquisition time ranged between 50s and 2 min 45s, depending on the basal heart rate and rhythm disturbances. Average processing time was 5min 7s. Adequate echographic visualization of the valve segments was more frequently obtained by 3D than by 2D TTE imaging (731/770 by 3D TTE vs. 693/770 by 2D TTE, $p<0.01$). The valve leaflets segments were more clearly identified by 3D TTE rather than 2D TTE (502/531 vs. 471/531, $p<0.01$). For adjacent commissures the results were similar by both methods (229/239 vs. 222/239, $p = 0.09$).

Table 1. *Baseline characteristics of the study group [data are presented as mean ± SD or No. (%)]*

Characteristics	Date
Age, years	52 ± 14
Woman/Male	43 (41%) / 61 (59%)
Body mass index, kg/m^2	27.3 ± 4.8
Heart rate, beats/min	73 ± 13
Atrial Fibrillation	44 (42%)
Mean blood pressure, mmHg	98.5 ± 14.2
New York Heart Association class	2.9 ± 0.7
LV ejection fraction (%)	49 ± 14
PSAP, mmHg	43.5 ± 16.7
Primary etiology:	
Mitral regurgitation	48 (46.2%)
Mitral stenosis	25 (24%)
Aortic regurgitation	12 (11.5%)
Aortic stenosis	19 (18.3%)

LV = left ventricle; PSAP = pulmonary systolic artery pressure

Total 3D TTE scores for the mitral and aortic valves were significantly better than 2D TTE scores (mean score 12.91 ± 1.62 by 3D vs 11.58 ± 1.02 by 2D, $p = 0.02$). This superiority of 3D TTE was irrespective of rhythm ($p < 0.05$ for both, sinus rhythm and atrial fibrillation). Using surgical classification as gold standard, the sensibility and specificity were 91% and 84 % for 3D TTE, and 85% and 77% for 2D TTE, respectively.

If we consider separately mitral valve, the mean 3D TTE scores was superior to 2D TTE (7.22 vs 6.16, $p = 0.03$). This superiority of 3D section persist for each leaflet: 2.78 vs 2.2 for the anterior leaflet ($p=0.03$), and 2.67 vs 2.19 for the posterior leaflet ($p=0.04$), respectively; for the commissures the differences were not statistically significant *(Fig. 1)*. For the aortic valve, it was not found a statistically significant difference between 3D TTE and 2D TTE (5.69 vesus 5.4, $p = 0.13$), but 3D was superior if we considered only the aortic leaflets *(Fig. 2)*: 2.85 vs 2.28, $p = 0.03$ (for the aortic commissures the score was 2.84 for 3D TTE vs 3.12 for 2D TTE, $p = 0.06$).

The main cause of mitral regurgitation was represented by flail in 21 patients (43.7%), prolapse *(Fig. 3)* in 15 patients (31.2%), tethering in 4 patients (8.3 %), valve perforation in 3 patients (6.2%), annular dilation in 3 patients (6.2%) and eroded leaflet edge in 2 patients (4.4%). The primary mechanism of mitral regurgitation was correct identified in 93% of patients by 3D reconstruction. Real-time 3D TTE was superior in its negative predictive value in terms of the correct

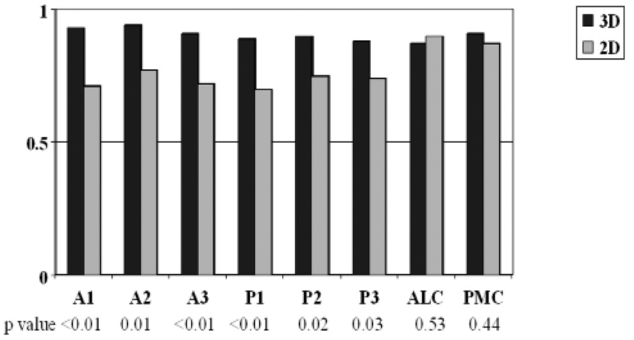

Figure 1. *Segmental recognition scores for live 3D TTE compared with 2D TTE in patients with mitral valvulopathy. P-values represent statistical differences between the mean scores for each segment obtained by the two modalities. A1 = Lateral scallop, A2 = Middle scallop and A3 = Medial scallop of the anterior mitral leaflet; P1= Lateral scallop, P2 = Middle scallop, and P3 = Medial scallop of the posterior mitral leaflet; ALC = Antero-lateral commissure; PMC = Postero-medial commissure*

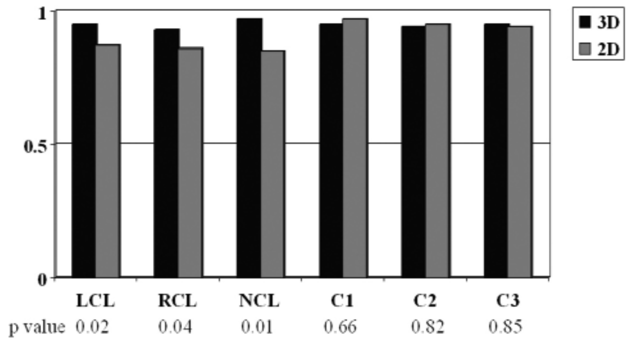

Figure 2. *Segmental recognition scores for live 3D TTE compared with 2D TTE in patients with aortic valvulopathy. P-values represent statistical differences between the mean scores for each segment obtained by the two modalities. LCL = Left coronary leaflet; RCL = Right coronary leaflet; NCL = Non-coronary leaflet; C1 = Commissure between left coronary leaflet and right coronary leaflet; C2 = Commissure between right coronary leaflet and non-coronary leaflet; C3 = Commissure between non-coronary leaflet and left coronary leaflet*

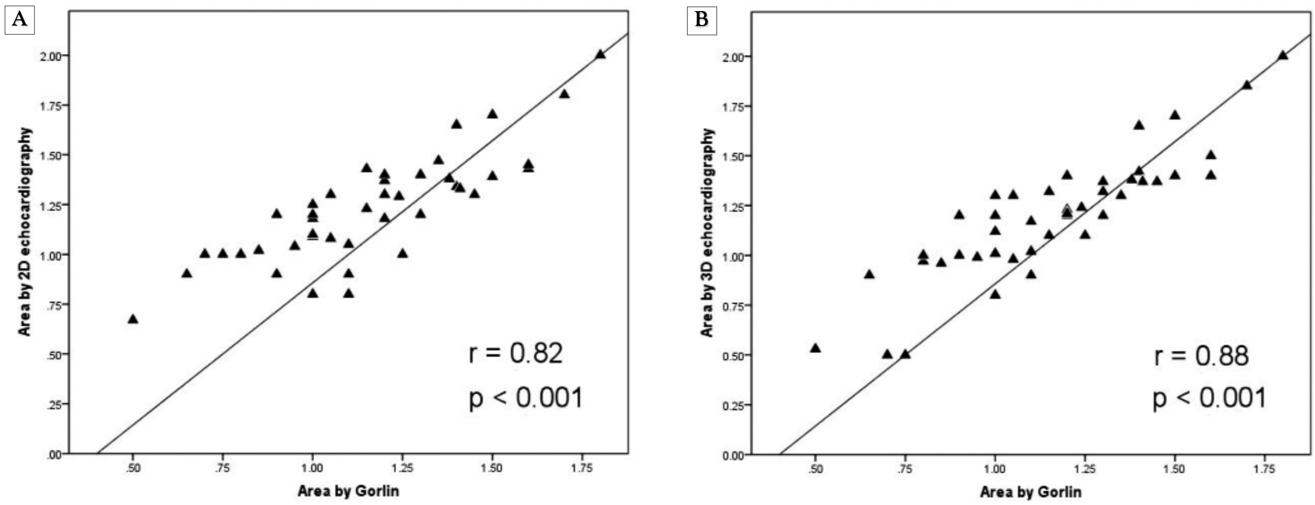

Figure 3. *Scatter plots with linear regression fit for valvular opening area determined by live 3D TTE and area determined invasively by Gorlin formula (**A**), and area determined by 2D TTE planimetry and that determined by Gorlin formula (**B**), in patients with valvular stenosis. The unit for all valvular areas is cm²*

recognition of 218 normal leaflet segments [196 (90%) segments accurately assigned as "normal" by 3D TTE vs 172 (79%) by 2D TTE, $p < 0.001$]. Posterior leaflet was most frequently affected in patients with degenerative valve disease, especially involving the P2 segment (20/48 patients, 42%).

The subgroup of patients with valvular stenosis (44 patients, 42%) was analyzed separately *(Fig. 4)*. The valvular opening area determined by 3D TTE showed better linear association with the area determined invasively by Gorlin formula ($r = 0.88$, $p < 0.001$) compared with 2D TTE ($r = 0.82$, $p < 0.001$) *(Fig. 5)*. As presented in *Fig.* 6, Bland-Altman analysis demonstrated a slightly closer agreement between area determined by 3D TTE and the area of stenosis determined invasive than between area determined by 2D TTE and area measured by Gorlin formula. For a concordance of 95%, it is to expect that less three points were out of the limits of agreement. No point in 3D ETT was in the limit zone, indicating good agreement with Gorlin formula. Both echo-cardiographic methods were significantly above the zero line, which means trend to overestimate with respect to area determined

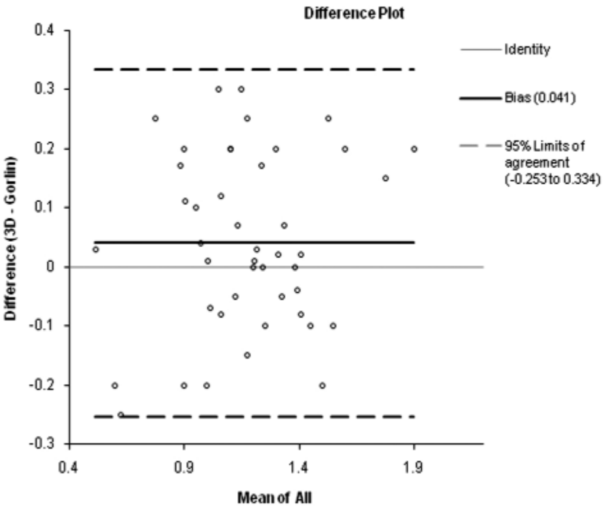

Figure 4. *Bland-Altman agreement plots comparing area determined by live 3D TTE and area determined inv sively by Gorlin formula (a), and area determined by 2D TTE planimetry and that determined by Gorlin formula (b), in patients with valvular stenosis*

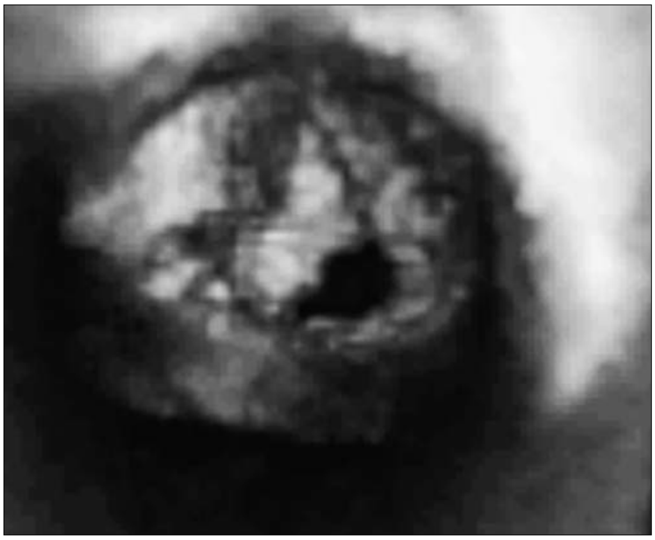

Figure 5. *3D real-time ETT image of a mitral valve with P3 and P2 prolapse*

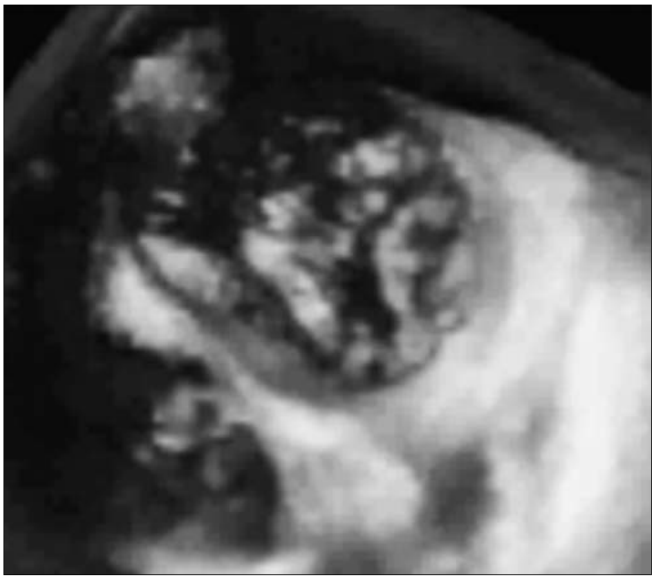

Figure 6. *3D real-time ETT image of a tricuspid, calcified aortic valve*

invasively by Gorlin formula. This trend is more exaggerate in bidimensional volumetric method, while 3D ETT reduces the overestimation.

Discussion

Understanding the morphology and function of the cardiac valves is essential for the optimal treatment of valvulopathies. We studied an unselected cohort of patients undergoing mitral and aortic surgery, irrespective of heart rhythm, with a representative array of etiologies typically encountered at a surgical centre and we observed a valuable incremental role of real-time 3D TTE over 2D TTE in the complete and accurate evaluation of mitral and aortic valve morphology prior to valve surgery. This study demonstrates also that 3D ETT is an accurate tool for area calculation and clinical decision-making in patients with valvular stenosis.

Conventional 2D TTE can diagnose valvular diseases, but can not show en face views of the leaflets, which can lead to difficulty defining the exact location of defect, and may result in difficulties communicating with surgeons. The detection of valvular lesion location in 2D examination may be influenced by the change of blood pressure (15). As shown in our study, 2D TTE is limited in its ability to completely visualize the aortic and mitral valve, in particular the commissures.

New generation 3D technology reduces the acquisition and reconstruction time to a few minutes and facilitates the visualization of the aortic and mitral valves (21). In the majority of cases in our study (94%), imaging quality was good or optimal and permitted 3D reconstruction. Using surgical classification as gold standard, we found a sensitivity of 91% and a specificity of 84% for the identification of valvular pathology using 3D TTE, a percentage comparable to previous studies (15-17,21). Interestingly, in our patients with adequate echographic window, 3D TTE was not different from 2D TTE in the identification of commissural pathologies (in aortic and mitral valvular disease), but was significantly superior in the evaluation of leaflet segments. There are several studies that showed similar results (9,17,20); in contrast, Hoole et al (23) and Muller et al (24) found that 3D TTE was excellent in identifying the commissures morphology of mitral valve, in particular if the transesophageal echocardiography was used.

Our study showed that live 3D TEE provides highly accurate online images for mitral regurgitation evaluation. A smaller area of prolapsing, especially if involving the A2 or

P2 segment, might be missed by the surgeon during inspection when the heart is arrested (25). Lesions on the posterior leaflet occur more frequently in patient with degenerative valve disease, especially involving the P2 segment. The results of this study add significantly to previously reported results indicating that the involvement of P2 segments/scallops is most often and frequently found in combined lesions (25-27). Other authors have reported (9) that in patients with mitral regurgitation, inspection of ''segmental'' accuracy showed superiority of 3D echocardiography for all anterior leaflet components and both commissures but not for the posterior leaflet.

The study has also demonstrated additional value for determination of maximal opening area of mitral and aortic valves. Planimetry of the valve orifice is the only direct measurement in 2D TTE. The success rate of mitral valve planimetry in 2D echocardiography has been reported to be as low as 75% depending on the study population (22,28). A major limitation of this method is the difficulty of defining the correct image plane that displays the true valve orifice. Thus, small changes of the transducer position on the chest wall and of its tilting and rotation result in significant changes of calculated orifice area. This is also the main reason that considerable experience and operator skill are necessary for the correct application of this method and why significant interobserver variability has been noted for these measurements (22). One of the most important advances in echocardiography during the last decade has been the development of matrix-array transducers able to perform volumetric imaging. Volumetric real-time echo is a novel imaging concept, which holds promise as a "breakthrough" technology for 3D echo. This technique allows instant (real-time) acquisition of a complete 3D data set without complex post-processing. 3D TTE reduces the potential sources of error (direct anatomic area calculation) and relies only on the quality of the apical acoustic window.

Bland-Altman analysis demonstrated in our study a good agreement between area determined by 3D TTE and the area of stenosis determined invasive by Gorlin formula. The both echocardiographic methods, 3D and 2D, were significantly above the zero line, which shows a tendency to overestimate with respect to area determined invasively by Gorlin formula. This tendency was more exaggerate in bidimensional volumetric method, while 3D ETT reduces the supraestimation. In contrast, several authors reported that 3D TTE yields statistically significant aortic area underestimation (13). Besides, there are hydrodynamic reasons to expect the aortic area by Gorlin to be slightly larger than by any echocardiographic method (13). Also, areas determined by 3D ETT echo were on average slightly smaller than those by 2D ETT; possibly, this fact simply reflects the greater potential of 3D echo to detect the true anatomic orifice area and the tendency of 2D echo to overestimate this area because of difficulties in defining the optimal imaging plane. In contrast to 2D echo, 3D ETT permits measurements from an apical window, and the interobserver variability for measurements with this technique appears to be significantly less than with 2D echo (22).

Therefore, this study confirms recent data showing that real-time 3D TTE may be integrated in the standard 2D examination facilitating the exact spatial localization of pathological structures and avoiding the need for mental reconstruction of 3D valve anatomy by the examiner.

Limitations

The number of patients in this study was relatively small; however, we were able to reach several significant observations. Patients were consecutively enrolled, but referral bias is possible and patients may not represent the whole population with significant mitral and/or aortic pathology. Furthermore, patients with larger valve areas in the moderate range are poorly represented in our sample. Considering invasive assessment of the aortic valve area by Gorlin's equation as the gold standard could be questioned, especially when pullback measurements substitute the ideal simultaneous left ventricular-aorta recordings. Once considered a gold standard, invasive measurement of valvular area with the Gorlin formula has demonstrated flaws20 and has been questioned as a clinical standard (29). Heart catheterization is now recommended only for a small subset of patients with nondiagnostic echocardiography or discrepancies with symptoms (30,31) a fact being reflected in current clinical practice (32).

Conclusions

Volumetric real-time 3D TTE provides accurate analysis of mitral and aortic diseases, and could be used not only for complete recognition of the valvular morphology but also for the accurate localisation and identification of pathology. Real-time 3D TTE appears to be superior to conventional echocardiographic techniques, particularly to planimetry using 2D ETT. Measurements are simple and can be performed within a few minutes.

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References

1. Ling LH, Enriquez-Sarano M, Seward JB, Tajik AJ, Schaff HV, Bailey KR, et al. Clinical outcome of mitral regurgitation due to flail leaflet. N Engl J Med. 1996;335(19):1417-23. Comment in: N Engl J Med. 1996;335(19):1456-8. N Engl J Med. 1997;336(18):1322-3; author reply 1323-4. N Engl J Med. 1997;336(18):1322; author reply 1323-4.
2. Ling LH, Enriquez-Sarano M, Seward JB, Orszulak TA, Schaff HV, Bailey KR, et al. Early surgery in patients with mitral regurgitation due to flail leaflets: a long term outcome study. Circulation. 1997;96(6):1819-25.
3. Pandian NG, Roelandt J, Nanda NC, Sugeng L, Cao QL, Azevedo J, et al. Dynamic three-dimensional echocardiography: methods and clinical potential. Echocardiography. 1994;11(3): 237-59.

4. Abraham TP, Warner JG Jr, Kon ND, Lantz PE, Fowle KM, Brooker RF, et al. Feasibility, accuracy, and incremental value of intraoperative three-dimensional transesophageal echocardiography in valve surgery. Am J Cardiol. 1997;80(12):1577-82.
5. Roelandt JR, Yao J, Kasprzak JD. Three-dimensional echocardiography. Curr Opin Cardiol. 1998;13(6):386-96.
6. Macnab A, Jenkins NP, Ewington I, Bridgewater BJ, Hooper TL, Greenhalgh DL, et al. A method for the morphological analysis of the regurgitant mitral valve using three-dimensional echocardiography. Heart. 2004;90(7):771-6.
7. Ahmed S, Nanda NC, Miller AP, Nekkanti R, Yousif AM, Pacifico AD, et al. Usefulness of transesophageal three-dimensional echocardiography in the identification of individual segment/scallop prolapse of the mitral valve. Echocardiography. 2003;20(2):203-9.
8. Godoy IE, Bednarz J, Sugeng L, Mor-Avi V, Spencer KT, Lang RM. Three dimensional echocardiography in adult patients: comparison between transthoracic and transesophageal reconstructions. J Am Soc Echocardiogr. 1999;12(12):1045-52.
9. Macnab A, Jenkins NP, Bridgewater BJ, Hooper TL, Greenhalgh DL, Patrick MR, et al. Three-dimensional echocardiography is superior to multiplane transoesophageal echo in the assessment of regurgitant mitral valve morphology. Eur J Echocardiogr. 2004; 5(3):212-22. Comment in: Eur J Echocardiogr. 2004;5(3):159-61.
10. Delabays A, Jeanrenaud X, Chassot PG, Von Segesser LK, Kappenberger L. Localization and quantification of mitral valve prolapse using three-dimensional echocardiography. Eur J Echocardiogr. 2004;5(6):422-9.
11. Fabricius AM, Walther T, Falk V, Mohr FW. Three-dimensional echocardiography for planning of mitral valve surgery: current applicability? Ann Thorac Surg. 2004;78(2):575-8.
12. Uno K, Takenaka K, Ebihara A, Nawata K, Hayashi N, Nagasaki M, et al. Value of live 3D transoesophageal echocardiography in the diagnosis of mitral valve lesions. Eur J Echocardiogr. 2009; 10(2):350-1. Epub 2008 Sep 11.
13. Gutiérrez-Chico JL, Zamorano JL, Prieto-Moriche E, Hernández-Antolín RA, Bravo-Amaro M, Pérez de Isla L, et al. Real-time three-dimensional echocardiography in aortic stenosis: a novel, simple, and reliable method to improve accuracy in area calculation. Eur Heart J. 2008;29(10):1296-306. Epub 2007 Nov 6.
14. de la Morena G, Saura D, Oliva MJ, Soria F, González J, García M, et al. Real-time three-dimensional transoesophageal echocardiography in the assessment of aortic valve stenosis. Eur J Echocardiogr. 2010;11(1):9-13. Epub 2009 Oct 4.
15. Pepi M, Tamborini G, Maltagliati A, Galli CA, Sisillo E, Salvi L, et al. Head-to-head comparison of two- and three-dimensional transthoracic and transesophageal echocardiography in the localization of mitral valve prolapse. J Am Coll Cardiol. 2006; 48(12):2524-30. Epub 2006 Nov 28.
16. Sharma R, Mann J, Drummond L, Livesey SA, Simpson IA. The evaluation of real-time 3-dimensional transthoracic echocardiography for the preoperative functional assessment of patients with mitral valve prolapse: a comparison with 2-dimensional transesophageal echocardiography. J Am Soc Echocardiogr. 2007;20(8):934-40. Epub 2007 Jun 6.
17. Tamborini G, Muratori M, Maltagliati A, Galli CA, Naliato M, Zanobini M, et al. Pre-operative transthoracic real-time three-dimensional echocardiography in patients undergoing mitral valve repair: accuracy in cases with simple vs. complex prolapse lesions. Eur J Echocardiogr. 2010;11(9):778-85. Epub 2010 May 20.
18. Carpentier A. Cardiac valve surgery--the "French correction". J Thorac Cardiovasc Surg. 1983;86(3):323-37.
19. Gorlin R, Gorlin SG. Hydraulic formula for calculation of the area of the stenotic mitral valve, other cardiac valves, and central circulatory shunts. Am Heart J. 1951;41(1):1-29.
20. Carabello BA. Advances in the hemodynamic assessment of stenotic cardiac valves. J Am Coll Cardiol. 1987;10(4):912-9.
21. Kondur A, Pitta S, Afonso L. Incremental utility of real-time three-dimensional echocardiography in the diagnosis and pre-operative assessment of cleft mitral valve in adults. Eur J Echocardiogr. 2008;9(4):586-8. Epub 2008 Mar 5.
22. Binder TM, Rosenhek R, Porenta G, Maurer G, Baumgartner H. Improved assessment of mitral valve stenosis by volumetric real-time three-dimensional echocardiography. J Am Coll Cardiol. 2000;36(4):1355-61. Comment in: J Am Coll Cardiol. 2000;36(4):1362-4.
23. Hoole SP, Liew TV, Boyd J, Wells FC, Rusk RA. Transthoracic real-time three-dimensional echocardiography offers additional value in the assessment of mitral valve morphology and area following mitral valve repair. Eur J Echocardiogr. 2008;9(5):625-30. Epub 2008 Mar 21.
24. Müller S, Müller L, Laufer G, Alber H, Dichtl W, Frick M, et al. Comparison of three-dimensional imaging to transesophageal echocardiography for preoperative evaluation in mitral valve prolapse. Am J Cardiol. 2006;98(2):243-8. Epub 2006 May 23.
25. Wei J, Hsiung MC, Tsai SK, Ou CH, Chang CY, Chang YC, et al. The routine use of live three-dimensional transesophageal echocardiography in mitral valve surgery: clinical experience. Eur J Echocardiogr. 2010;11(1):14-8. Epub 2009 Nov 21.
26. El Khoury G, Noirhomme P, Verhelst R, Rubay J, Dion R. Surgical repair of prolapsing anterior leaflet in degenerative mitral disease. J Heart Valve Dis. 2000;9(1):75-80; discussion 81. Comment in: J Heart Valve Dis. 2000;9(5):738-9.
27. Rankin JS, Sharma MK, Teague SM, McLaughlin VW, Johnston TS, McRae AT. A new approach to mitral valve repair for rheumatic disease: preliminary study. J Heart Valve Dis. 2008; 17(6):614-9.
28. García-Orta R, Moreno E, Vidal M, Ruiz-López F, Oyonarte JM, Lara J, et al. Threedimensional versus two-dimensional transesophageal echocardiography in mitral valve repair. J Am Soc Echocardiogr. 2007;20(1):4-12.
29. Chambers J, Bach D, Dumesnil J, Otto C, Shah P, Thomas J. Crossing the aortic valve in severe aortic stenosis: no longer acceptable? J Heart Valve Dis. 2004;13(3):344-6.
30. Vahanian A, Baumgartner H, Bax J, Butchart E, Dion R, Filippatos G, et al. Guidelines on the management of valvular heart disease: The Task Force on the Management of Valvular Heart Disease of the European Society of Cardiology. Eur Heart J. 2007;28(2):230-68. Epub 2007 Jan 26. Comment in: Eur Heart J. 2007;28(10):1267; author reply 1267-8. Eur Heart J. 2007;28(20):2552-3; author reply 2553-4.
31. Bonow RO, Carabello BA, Chatterjee K, de Leon AC Jr, Faxon DP, Freed MD, et al. 2008 focused update incorporated into the ACC/AHA 2006 guidelines for the management of patients with valvular heart disease: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Writing Committee to revise the 1998 guidelines for the management of patients with valvular heart disease). Endorsed by the Society of Cardiovascular Anesthesiologists, Society for Cardiovascular Angiography and Interventions, and Society of Thoracic Surgeons. J Am Coll Cardiol. 2008;52(13): e1-142.
32. Iung B, Baron G, Butchart EG, Delahaye F, Gohlke-Bärwolf C, Levang OW, et al. A prospective survey of patients with valvular heart disease in Europe: The Euro Heart Survey on Valvular Heart Disease. Eur Heart J. 2003;24(13):1231-43.