

Three Dimensional Echocardiographic Analysis of Mitral Valve Characteristics

Análisis de las características de la válvula mitral en ecocardiograma tridimensional

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ABSTRACT

Introduction: Three-dimensional transesophageal echocardiography (3D TEE) is a useful tool, particularly for the evaluation of mitral valve disease. There are few reports in the literature, none of our country, about the normal values in order to define the disease.

Objective: The aim of this study was to define the normal values of the mitral valve annulus and leaflets in a population without heart disease using 3D TEE.

Methods: Twenty-six patients without heart disease were prospectively included and underwent two-dimensional and 3D TEE. The best 3D volume acquired was used to construct a three dimensional model of the mitral valve to measure the mitral valve leaflets and annulus (indexed for body surface area). Data are presented as median with interquartile range.

Results: Age was 64.5 years (39.1-69.7) and 46% were men. Mitral annulus measurements were: intercommissural diameter 18.7 mm (16.5-19.9), anteroposterior diameter 16.4 mm (15.1-17.8), height 4.4 mm (3.6-5.4), circumference in projection plane 55.1 mm (52.2-60), 3D circumference 57.8 mm (55.5-64.1), area in projection plane 433.9 mm² (405.3-489) and 3D area 457.8 mm² (431.2-515.8). The leaflet measurements were: anterior leaflet length 13.4 mm (12.4-14), anterior leaflet area 328.6 mm² (297-359.8), posterior leaflet length 7.8 mm (7.1-8.3) and posterior leaflet area 242 mm² (214.3-265.5). The reproducibility of 3D mitral annulus measurements was evaluated and showed good intraobserver and interobserver agreement.

Conclusions: Results show reference values of the mitral valve leaflets and annulus estimated by 3D TEE in a population without heart disease. These data lay the foundations for future studies which, by associating similar measurements across all the ranges of severity of mitral valve disease, may prospectively define the sensitivity and specificity of the method for mitral valve assessment.

Key words: Echocardiography, Transesophageal - Echocardiography, Three-Dimensional - Echocardiography, Mitral Valve Insufficiency

RESUMEN

Introducción: El ecocardiograma transesofágico en tres dimensiones (ETE 3D) es una herramienta especialmente útil en el estudio de la patología de la válvula mitral. En la bibliografía existe poca información, ninguna de nuestro país, acerca de los valores normales a partir de los cuales se pueda definir la enfermedad.

Objetivo: Definir los valores normales de las medidas del anillo y de las valvas de la válvula mitral a través del estudio de una población sin cardiopatía utilizando el ETE 3D.

Material y métodos: Se incluyeron prospectivamente 26 pacientes sin patología cardiovascular que fueron estudiados con ETE en dos y tres dimensiones. Con el mejor volumen 3D adquirido se construyó un modelo tridimensional de la válvula mitral del que se obtuvieron las medidas de las valvas y del anillo (indexadas por superficie corporal). Los datos se presentan como mediana con rango intercuartil.

Resultados: La edad fue de 64,5 años (39,1-69,7), el 46% eran hombres. Las medidas del anillo mitral fueron: diámetro intercomisural 18,7 mm (16,5-19,9), diámetro anteroposterior 16,4 mm (15,1-17,8), altura 4,4 mm (3,6-5,4), circunferencia en un plano 55,1 mm (52,2-60), circunferencia en 3D 57,8 mm (55,5-64,1), área en un plano 433,9 mm² (405,3-489) y área en 3D 457,8 mm² (431,2-515,8). Las medidas de las valvas fueron: longitud de la valva anterior 13,4 mm (12,4-14), área de la valva anterior 328,6 mm² (297-359,8), longitud de la valva posterior 7,8 mm (7,1-8,3) y área de la valva posterior 242 mm² (214,3-265,5). Se evaluó la reproducibilidad de las mediciones del anillo mitral en 3D y se observó muy buena concordancia tanto intraobservador como interobservador.

Conclusiones: Los resultados muestran los valores de referencia de las valvas y del anillo de la válvula mitral en una población sin cardiopatía estudiada con ETE 3 D. Sientan las bases para futuros estudios que, asociando mediciones similares en todo el rango de gravedad de la patología mitral, permitan definir prospectivamente la sensibilidad y la especificidad del estudio para enfermedad mitral.

Palabras clave: Ecocardiografía transesofágica - Ecocardiografía tridimensional - Válvula mitral - Insuficiencia de la válvula mitral.

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Abbreviations

2D	Two-dimensional	TEE	Transesophageal echocardiography
3D	Three-dimensional	CS	Body surface area
LA	Left atrium	LV	Left ventricle

INTRODUCTION

Degenerative mitral valve disease is a prevalent condition, particularly in the elderly. (1, 2) The evaluation of this disease constitutes a permanent challenge for echocardiography, which is currently the technique most widely used in the assessment of heart valve diseases. (3) In the scenario of mitral valve regurgitation, echocardiography provides valuable information about the etiology, lesions, severity and extension of the disease. These data are particularly useful at the moment of evaluating the feasibility of eventual mitral valve repair. (4-6) Two-dimensional echocardiography (2D echo) is the most commonly used tool; yet, the technique has certain limitations to quantify a complex three-dimensional structure as the mitral valve apparatus. (7) The recent development of three-dimensional transesophageal echocardiography (3D TEE) has made it possible to overcome such shortcomings. (8) Multiple views are necessary to characterize valve anatomy using 2D echo, with or without color Doppler, while 3D TEE obtains high-quality three-dimensional real time images of the mitral valve. (9) Although the visualization of three-dimensional mitral valve real anatomy and leaflet motion is important and revealing, the greatest virtue of 3D TEE lies in its ability to make a valid and reproducible quantification of each of the components of the mitral valve apparatus. (9) Thus, the real three-dimensional structure of the annulus, leaflets and subvalvular apparatus can be measured.

The development of criteria for establishing the presence of heart valve disease demands definitions of “normality” and “abnormality”. There are few reports in the literature, none of our country, with a small number of cases, about the normal mitral valve values used to define mitral valve disease with 3D TEE. (10-13) The aim of this study was to define the normal values of the mitral valve annulus and leaflets in a population without heart disease using 3D TEE.

METHODS

The study was approved by the Institutional Review Board, and all the patients signed an informed consent form before participating in the study.

Between June 2008 and December 2011, 26 patients were prospectively included. All the patients had been referred to our laboratory for TEE evaluation and were considered subjects without heart disease. The test had been ordered to examine a cardioembolic source in 16 patients and due to febrile syndrome in 10.

The following inclusion criteria were considered to define healthy patients, without heart disease:

1. Presence of sinus rhythm.
2. Left ventricular (LV) diastolic dimension < 56 mm.
3. Preserved LV systolic function (ejection fraction > 55%).
4. Absence of segmental wall motion abnormalities.
5. Absence of heart valve stenosis.
6. Absence of heart valve regurgitations greater than grade I/IV (mild).
7. Absence of pulmonary hypertension (pulmonary systolic pressure > 40 mm Hg).

All the patients underwent transthoracic Doppler echocardiography, and next, TEE was performed following standard technique. The test was performed in two-dimensional mode, color Doppler, pulsed wave and continuous wave Doppler. Then, three-dimensional data set sequences from the mitral valve apparatus were acquired, two in 3D zoom mode and two in live mode. The acquisition of the 3D images required two additional minutes. The echocardiographic evaluation was performed with a Philips iE33 ultrasound system equipped with X7-2t transesophageal echocardiography matrix transducer (Philips Medical Systems, Andover, MA). The images were digitized and transferred to a workstation equipped with software for quantification of the mitral valve (Q-Lab 9.0 Philips Medical Systems). The best sequence acquired in the 3D zoom mode was used to construct a three-dimensional model of the mitral valve in end-systole. The measurements of the mitral valve leaflets and annulus were obtained from this model. End-systole was defined as the last frame with the open aortic valve. To reconstruct the model, the mitral valve was automatically transected in three orthogonal planes (Figure 1 A). Next, 4 reference points were tagged on the mitral annulus (anterolateral, posteromedial, anterior and posterior) and then 20 additional sites were tagged on 10 rotational planes to complete 24 points which defined the three-dimensional shape of the annulus. The mitral valve volume was subsequently segmented in multiple parallel planes from the anterolateral commissure to the posteromedial commissure using cross-sections every 2.5 mm (Figure 1 B). Points were assigned to the leaflets in each of these planes. The reconstructed valve model was displayed as a color-coded 3D-rendered surface representing a topographical map of the leaflets and mitral annulus (Figure 2). Then, the software performed automated measurement of the dimensions, geometry and areas of the mitral annulus and leaflets. In each patient, mitral valve annulus measurements included: intercommissural diameter, anteroposterior diameter, height (distance in mm between the highest and the lowest insertion point of the mitral annulus), circumference in the projection plane, 3D circumference, area in the projection plane, 3D area and height to intercommissural diameter ratio (saddle shape measurement). The leaflet measurements included: anterior leaflet length and area, posterior leaflet height and area, tenting height (distance from the annular plane to the lowest mitral valve coaptation point in the ventricle), tenting volume (volume enclosed between the annular plane and mitral leaflets towards the ventricle), prolapse height (distance between the mitral annular plane and the highest mitral leaflet coaptation point in the left atrium) and prolapse volume (volume enclosed between the annular plane and mitral leaflets towards the atrium). All the measurements were indexed for body surface area (BSA). The DuBois formula was used to calculate BSA.

Fig. 1. A. Reference points tagged to the mitral annulus. Four initial reference points are tagged in two orthogonal planes of the valve volume in end-systole: anterolateral and posteromedial (top left); anterior and posterior (top right). **B.** Mitral valve volume segmented in multiple parallel planes from the lateral region to the medial region. In each plane, reference points are tagged on the leaflets (top right).

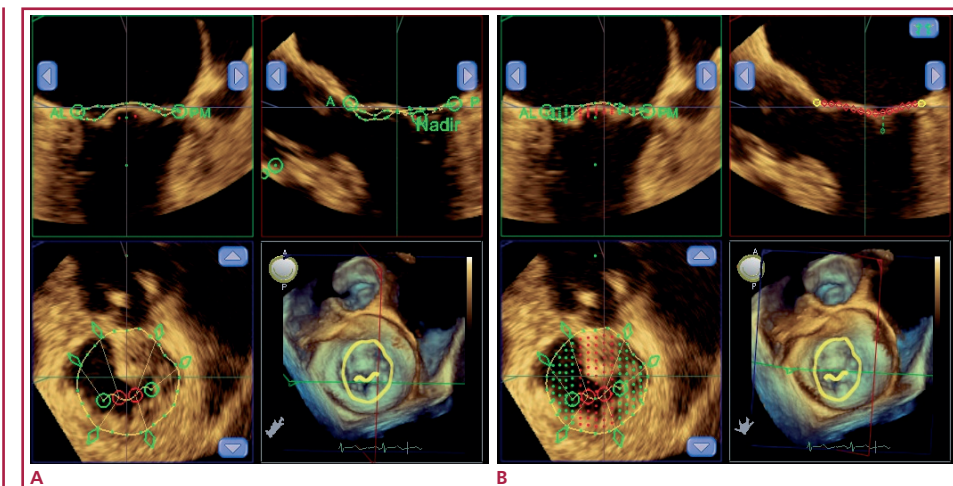
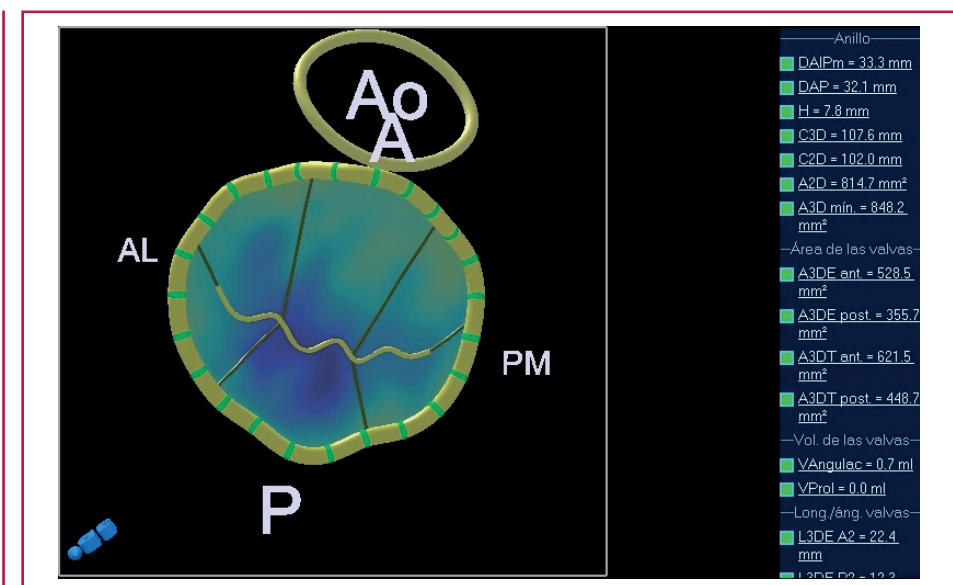


Fig. 2. Three-dimensional reconstruction model of the mitral valve in end-systole using the quantification software. A: Anterior. AL: Anterolateral. AV: Aortic valve. P: Posterior. PM: Posteromedial.



Data are presented as median with interquartile range.

The reproducibility of 3D mitral annulus measurements was evaluated in all the patients. Intraobserver variability was evaluated with a second measurement performed by the same observer. Interobserver variability was analyzed by repeating the analysis of all the measurements by a second observer, who was blinded to the previous results. Intraobserver and interobserver agreement was assessed by the intraclass correlation coefficient. The level of agreement was defined as: poor < 0.4, fair to good from 0.4 to 0.75 and very good > 0.75. (14, 15) A bootstrapping resampling method with 1000 repetitions was used to obtain the correlation coefficients.

The statistical analysis was performed using STATA 10.0 software package.

RESULTS

Mean age was 64.5 years (39.1-67.9 years); 46% were men and BSA was 1.84 m² (1.7-2.03 m²). The following echocardiographic measurements were obtained: LV diastolic dimension 25.7 mm (23.5-26.9 mm), LV systolic dimension 14.2 mm (13-16.2 mm), LV shorten-

ing fraction 43.6% (38.6-46.5%), LV ejection fraction 63.7% (60-67%), left atrial (LA) dimension 19.5 mm (17.3-21.8 mm) and LA area 10.9 cm² (9-12.6 cm²). Table 1 shows leaflet and annulus measurements obtained with the 3D reconstruction model of the mitral valve in end-systole. All the parameters could be measured in all the cases.

The intraobserver agreement was very good for all the 3D mitral annulus variables measured. The interobserver agreement was good for the anteroposterior diameter measurement and very good for the rest of the parameters (Table 2).

DISCUSSION

Degenerative mitral valve disease is a common condition and its prevalence is constantly rising as the general population increases in number and age. (1, 2) Publications from the United States and Europe show that the presence of this disease produces a significant increase in morbidity and mortality rates. (1, 2, 16)

Mitral valve repair has changed the natural history of mitral regurgitation and improved patient survival. (17, 18) The procedure success rate depends on the valve anatomy, and mostly on the surgeon's ability and experience. (19, 20) In this setting, it is essential to thoroughly understand heart valve disease (etiology, lesions, dysfunction mechanism and extent of the disease) in order to pose an adequate management strategy and refer those patients with the most severe disease to the most experienced centers. (21, 22) The correct anatomic definition of heart valve disease is extremely useful for the surgeon at the moment of planning the surgical approach. In this sense, 3D TEE plays a crucial role. (22-25) This technology not only allows the visualization of real time three-dimensional images of the mitral valve apparatus and leaflet motion with exquisite anatomic definition, but also enables a real and reproducible quantification of each of the components of the mitral valve apparatus. (22)

Table 1. Mitral valve leaflet and annulus measurements obtained with the three-dimensional reconstruction model of the mitral valve in end-systole

Mitral annulus parameters	Median (interquartile range)
Intercommissural diameter, mm/m ² BSA	18.7 (16.5-19.9)
Anteroposterior diameter, mm/m ² BSA	16.4 (15.1-17.8)
Height, mm/m ² BSA	4.4 (3.6-5.4)
Circumference in projection plane, mm/m ² BSA	55.1 (52.2-60)
3D circumference, mm/m ² BSA	57.8 (55.5-64.1)
Area in projection plane, mm/m ² BSA	433.9 (405.3-489)
3D area, mm/m ² BS	457.8 (431.2-515.8)
Height/intercommissural diameter ratio (*)	0.23 (0.21-0.27)
Leaflet parameters	
Anterior leaflet length, mm/m ² BSA	13.4 (12.4-14)
Anterior leaflet area, mm/m ² BSA	328.6 (297-359.8)
Posterior leaflet length, mm/m ² BSA	7.8 (7.1-8.3)
Posterior leaflet area, mm/m ² BSA	242 (214.3-265.5)
Tenting height, mm/m ² BSA	1.59 (1.1-2.24)
Tenting volume, ml/m ² BSA	0.29 (0.12-0.41)
Prolapse height, mm/m ² BSA	0.7 (0.39-1.41)
Prolapse volume, ml/m ² BSA	0.05 (0-0.21)

BSA: Body surface area * Expresses annular saddle shape measurement

Another advantage of the technique is that the images are easily recognized by the surgeon and the interventional cardiologist, who can discuss the possible strategies with the attending physicians. The method has been widely accepted by the medical community and its use has rapidly expanded. All the advantages of the technique have made 3D TEE the procedure of choice for the evaluation of mitral valve disease, and therefore, it is necessary to establish reference values for the general population in order to define the disease. (26, 27) The present study was conducted to determine the dimensions and characteristics of the mitral valve apparatus estimated by 3D TEE in a population without heart disease. The information here presented about the dimensions, areas and shape of the mitral valve apparatus and leaflets in patients without heart disease is useful for the development of criteria to establish the presence of the disease from the definition of the normality.

There are few publications about the dimensions, areas and shape of the mitral valve annulus in patients without heart disease, all of them from abroad. In these experiences, the patients without heart disease were used as controls of patients with degenerative mitral valve disease. (10-12) Moreover, in these publications, as opposed to our investigation, the number of patients without heart disease was lower, only two of them reported leaflet measurements, and in none of them the measurements were indexed for BSA.

Of importance, the software used defines prolapse as the presence of billowing (protrusion of the leaflet body or the entire body into the atrium beyond the mitral annular plane) even in the absence of true prolapse (protrusion of the free edge of the leaflet beyond the mitral annular plane). For this reason, we can find small portions of the leaflet body beyond the mitral annular plane at end-systole even in healthy populations without heart disease. In our study, the median prolapse height was 0.7 mm/m² BSA and median prolapse volume was 0.05 ml/m² BSA. In the study by Chandra et al., (12) median prolapse height in the healthy population was 0.27 mm, lower than in our experience.

With 3D TEE, images can be acquired in 3D live mode or 3D zoom mode. Acquisitions in live mode require the presence of regular rhythm and adequate breath-holding. Then, at least four subvolumes obtained in four successive beats are assembled, creating

Mitral annulus parameters	Intraobserver agreement (95% CI)	Interobserver agreement (95% CI)
Area in projection plane	0.976 (0.946-0.989)	0.859 (0.746-0.924)
3D area	0.960 (0.939-0.983)	0.851 (0.758-0.911)
Circumference in projection plane	0.954 (0.894-0.981)	0.849 (0.741-0.914)
3D circumference	0.936 (0.876-0.967)	0.831 (0.744-0.890)
Intercommissural diameter	0.885 (0.732-0.953)	0.795 (0.539-0.916)
Anteroposterior diameter	0.928 (0.863-0.963)	0.657 (0.445-0.800)

Table 2. Intraclass correlation coefficient, and intraobserver and interobserver variability for the three-dimensional measurements of the mitral valve annulus

a pyramidal volume containing the data of the study structure. The advantage of this acquisition method is that the pyramidal volume contains more data and, thus, has greater temporal and spatial resolution. In transesophageal studies, the disadvantages are related to the risk of creating stitching artifacts due to the patients' inability to stay still and hold their breath, particularly when they are under the effects of anesthesia, or due to the presence of arrhythmias. On the contrary, mitral valve acquisitions in 3D zoom mode do not present these issues; they do not require apnea or ECG gating, although the pyramid obtained has fewer frames per second (between 5 and 10). However, the 3D zoom mode is the modality most commonly used for the evaluation of the mitral valve in the catheterization laboratory and operating room as it allows "in vivo" visualization of the structures evaluated. (9) We chose the 3D zoom mode despite its lower temporal and spatial resolution because we preferred not to have stitching artifacts. Other authors have reported different experiences: while Grewal et al. (11) and Maffessanti et al. (13) used the 3D live mode with their patients, Chandra et al. (12) preferred the 3D zoom mode. On the other hand, Moustafa et al. (10) used acquired volumes either in 3D zoom mode or in 3D live mode.

The construction of the three-dimensional model of the mitral valve can be achieved after a short training period and requires about 15 minutes per patient. The reproducibility of the mitral valve annulus dimensions, circumferences, areas, height and shape estimations is high, as demonstrated by the good intraobserver and interobserver agreement.

CONCLUSIONS

The results of the present study show the reference values of the mitral valve leaflet and annulus dimensions, circumference, area, height and shape estimated by 3D TEE in a population without heart disease. These data lay the foundations for future studies which, by associating similar measurements across all the ranges of severity of mitral valve disease, may prospectively define the sensitivity and specificity of the method for mitral valve assessment.

Conflicts of interest

None declared.

REFERENCES

- Nkomo VT, Gardin JM, Skelton TN, Gottdiener JS, Scott CG, Enriquez-Sarano M. Burden of valvular heart diseases: a population-based study. *Lancet* 2006;368:1005-11. <http://doi.org/dhzdrf>
- Iung B, Baron G, Tornos P, Gohlke Bärwolf C, Butchart EG, et al. Valvular heart disease in the community: A European experience. *Curr Probl Cardiol* 2007;32:609-61. <http://doi.org/chtr59>
- Bonow RO, Carabello BA, Chatterjee K, de León AC, 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). *J Am Coll Cardiol* 2008;52:e1-e142. <http://doi.org/bw957v>
- Shah PM. Current concepts in mitral valve prolapse Diagnosis and management. *J Cardiol* 2010;56:125-33. <http://doi.org/bh9p8x>
- Verma S, Mesana TG. Mitral-valve repair for mitral-valve prolapse. *N Engl J Med* 2009;361:2261-9. <http://doi.org/bdxbkbd>
- Filsoufi F, Carpentier A. Principles of reconstructive surgery in degenerative mitral valve disease. *Semin Thorac Cardiovasc Surg* 2007;19:103-10. <http://doi.org/dk5w89>
- Veronesi F, Corsi C, Sugeng L, Mor-Avi V, Caiani EG, Weinert L, et al. A study of functional anatomy of aortic-mitral valve coupling using 3D matrix transesophageal echocardiography. *Circ Cardiovasc Imaging* 2009;2:24-31. <http://doi.org/brsnz4>
- Mor-Avi V, Sugeng L, Lang RM. Contemporary reviews in cardiovascular medicine real-time 3-dimensional echocardiography: An integral component of the routine echocardiographic examination in adult patients? *Circulation* 2009;119:314-29. <http://doi.org/fg4m77>
- Lang RM, Badano LP, Tsang W, Adams DH, Agricola E, Buck T, et al. EAE/ASE recommendations for image acquisition and display using three-dimensional echocardiography. *J Am Soc Echocardiogr* 2012;25:3-46. <http://doi.org/dt5z3f>
- Moustafa SE, Mookadam F, Alharthi M, Kansal M, Bansal RC, Chandrasekaran K. Mitral annular geometry in normal and myxomatous mitral valves: three-dimensional transesophageal echocardiographic quantification. *J Heart Valve Dis* 2012;21:299-310.
- Grewal J, Suri R, Mankad S, Tanaka A, Mahoney DW, Schaff HV, et al. Mitral annular dynamics in myxomatous valve disease: new insights with real-time 3-dimensional echocardiography. *Circulation* 2010;121:1423-31. <http://doi.org/d4p2m6>
- Chandra S, Salgo IS, Sugeng L, Weinert L, Tsang W, Takeuchi M, et al. Characterization of degenerative mitral valve disease using morphologic analysis of real-time three-dimensional echocardiographic images. Objective insight into complexity and planning of mitral valve repair. *Circ Cardiovasc Imaging* 2011;4:24-32. <http://doi.org/c9qfsh>
- Maffessanti F, Marsan NA, Tamborini G, Sugeng L, Caiani EG, Gripari P, et al. Quantitative analysis of mitral valve apparatus in mitral valve prolapse before and after annuloplasty: a three-dimensional intraoperative transesophageal study. *J Am Soc Echocardiogr* 2011;24:405-13. <http://doi.org/d329cv>
- Fleiss JL. The design and analysis of clinical experiments. New York: Wiley; 1986.
- Prieto L, Lamarca R, Casado A. Assessment of the reliability of clinical findings: the intraclass correlation coefficient. *Med Clin (Barc)* 1998;110:142-5.
- 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;335:1417-23. <http://doi.org/ftq9jz>
- Gammie JS, Sheng S, Griffith BP, Peterson ED, Rankin JS, O'Brien SM, et al. Trends in mitral valve surgery in the United States: Results from the Society of Thoracic Surgeons Adult Cardiac Database. *Ann Thorac Surg* 2009;87:1431-9. <http://doi.org/bffsbq>
- Enriquez-Sarano M, Schaff HV, Orszulak TA, Tajik AJ, Bailey KR, Frye RL. Valve repair improves the outcome of surgery for mitral regurgitation. A multivariate analysis. *Circulation* 1995;91:1022-8. <http://doi.org/sgp>
- Bolling SF, Li S, O'Brien SM, Brennan JM, Prager RL, Gammie JS. Predictors of mitral valve repair: clinical and surgeon factors. *Ann Thorac Surg* 2010;90:1904-11. <http://doi.org/drj95>
- David TE. Outcomes of mitral valve repair for mitral regurgitation due to degenerative disease. *Semin Thorac Cardiovasc Surg* 2007;19:116-20. <http://doi.org/c6t2cb>
- Adams DH, Rosenhek R, Falk V. Degenerative mitral valve regurgitation: best practice revolution. *Eur Heart J* 2010;31:1958-66. <http://doi.org/cmd5pf>
- Adams DH, Anyanwu AC, Sugeng L, Lang RM. Degenerative mitral valve regurgitation: surgical echocardiography. *Curr Cardiol Rep* 2008;10:226-32. <http://doi.org/dtf3mb>
- O'Gara P, Sugeng L, Lang R, E. Sarano M, Hung J, Raman S, et al. The role of imaging in chronic degenerative mitral regurgitation. *JACC Imag* 2008;1:221-37. <http://doi.org/bx5b5n>

24. Grewal J, Mankad S, Freeman WK, Click RL, Suri RM, Abel MD, et al. Real-time three-dimensional transesophageal echocardiography in the intraoperative assessment of mitral valve disease. *J Am Soc Echocardiogr* 2009;22:34-41. <http://doi.org/dnwdn6>
25. Biaggi P, Jedrzkiewicz S, Gruner C, Meineri M, Karski J, Vegas A, et al. Quantification of mitral valve anatomy by three-dimensional transesophageal echocardiography in mitral valve prolapse predicts surgical anatomy and the complexity of mitral valve repair. *J Am Soc Echocardiogr* 2012;25:758-65. <http://doi.org/sgq>
26. Ben Zekry S, Nagueh SF, Little SH, Quinones MA, McCulloch ML, Karanbir S, et al. Comparative accuracy of two- and three-dimensional transthoracic and transesophageal echocardiography in identifying mitral valve pathology in patients undergoing mitral valve repair: initial observations. *J Am Soc Echocardiogr* 2011;24:1079-85. <http://doi.org/bwrfx5>
27. Castillo JG, Solís J, González-Pinto A, Adams DH. Surgical Echocardiography of the Mitral Valve. *Rev Esp Cardiol* 2011;64:1169-81. <http://doi.org/dktb7s>