

Assessment of left ventricular outflow tract dynamics during the cardiac cycle by three-dimensional echocardiography

MARIANO FALCONI^{MTSAC}, DIEGO FUNES[†], ANÍBAL ARIAS, RODRIGO BAGNATI[†], GUILLERMO JAIMOVICH, MAURO GIACOMINI, PABLO OBERTI^{MTSAC}, ARTURO CAGIDE^{MTSAC}

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Address for reprints:

Dr. Mariano L. Falconi
Sección Imágenes Cardiovasculares
Servicio de Cardiología
Instituto de Medicina
Cardiovascular
Hospital Italiano de Buenos Aires
(C1199ABB) Juan D. Perón 4190
Tel. (54 11) 4959-0200 (ext. 8820)

ABSTRACT

Background

Anatomical and anatomic-functional disorders of the left ventricular outflow tract (LVOT) are subject of numerous studies. However, LVOT normal dynamic behavior, especially in procedures involving its area is also relevant, and may be evaluated with new three-dimensional imaging methods.

Objective

The aim of this study was to assess LVOT dynamics during the cardiac cycle with three-dimensional transesophageal echocardiography (TEE).

Methods

Forty two patients referred for transesophageal echocardiography (TEE) were prospectively included. All TEE studies were performed with a three-dimensional transesophageal probe. For full-volume images, 4 gated beats were acquired for off-line analysis. The cardiac cycle was divided in proto-systole (S1), mid-systole (S2) and tele-systole (S3) and proto-diastole (D1), mid-diastole (D2) and tele-diastole (D3). The LVOT area was measured by planimetry of the short axis, through orthogonal sections to the LVOT long axis in each phase.

Results

Mean age was 67 ± 10 years, and 63% of the patients were male. The LVOT area (cm^2) in the different phases of the cardiac cycle was: S1: 4.44 ± 1.02 ; S2: 4.15 ± 0.91 ; S3: 3.9 ± 0.89 ; D1: 3.76 ± 0.98 ; D2: 3.89 ± 1.04 ; D3: 4.34 ± 1.11 . Maximum area was observed in S1, corresponding to the closed position of the anterior leaflet of the mitral valve (AML) and reduced motion of the interventricular septum (IVS) towards LVOT; minimum area was obtained in D1 consistent with a certain persistence of the IVS in the LVOT and maximal AML opening occupying part of the LVOT. Total area reduction was $15 \pm 11\%$ ($p < 0.0001$), changing the LVOT from a partially elliptical or circular shape (systole) to a markedly elliptical or semilunar one (diastole).

Conclusion

The LVOT modifies its area and shape during the cardiac cycle, depending basically on IVS excursion during systole and mitral valve opening during diastole.

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Key words > Heart Ventricles - Three-Dimensional Echocardiography – Physiology

Abbreviations >

AAVA	Aortic valve area	MSCT	Multislice computed tomography
3D TE Echo	Three-dimensional transesophageal echocardiography	LVOT	Left ventricular outflow tract
IVS	Interventricular septum	AML	Anterior mitral leaflet

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Cardiovascular Imaging Unit and Department of Cardiology, Institute of Cardiovascular Medicine, Hospital Italiano de Buenos Aires

^{MTSAC} Full member of the Argentine Society of Cardiology

[†] To apply as full member of the Argentine Society of Cardiology

BACKGROUND

The left ventricular outflow tract (LVOT) is a structure mainly limited by the interventricular septum and the anterior mitral valve leaflet, where the systolic flow is directed prior to its outflow through the aortic valve. Both LVOT limits are very mobile (especially the anterior leaflet of the mitral valve) and thus it is expected that the LVOT changes both its dimensions and shape during the cardiac cycle.

The LVOT is frequently involved in anatomical and anatomic-functional disorders (anterior systolic septal motion, sub-aortic membranes). However, its normal dynamic behavior is also relevant, especially in procedures involving its area, as percutaneous aortic valve prosthesis grafting where, depending on the model, a variable portion of the prosthetic structure lies in the LVOT. The purpose of this study was to evaluate the changes in LVOT total area and shape during the cardiac cycle by three-dimensional transesophageal echocardiography.

METHODS

Forty-two patients, > 18 years of age and with normal sinus rhythm at the time of the study, referred for transesophageal echocardiography, were prospectively included between June 2010 and March 2011. Patients with structural or functional disorders that could affect LVOT dynamics, as history of percutaneous aortic valve grafting, cardiac surgery with pericardial opening, aortic or mitral valve replacement, alcohol septal ablation, myocardial infarction with anterior septal involvement, left bundle branch block, anterior systolic mitral motion, mitral stenosis, ventricular dysfunction (ejection fraction < 50%, and frequent ventricular or supraventricular arrhythmia were excluded from the study.

Multiplanar transesophageal echocardiography was performed using a Philips IE 33 echocardiography system (Philips Ultrasound, Bothell WA, USA) and a transesophageal X7-2t probe that enabled conventional and three-dimensional acquisitions (in real time, real time zoom, complete volume and orthogonal planes). LVOT analysis was made employing "full-volume images" for off-line analysis.

Studies were performed under topical lidocaine spray and gel anesthesia in the left lateral decubitus position, after fasting for at least 6 hours. Patients were connected to electrocardiographic monitoring continuous to the echocardiography equipment to acquire gated images. A conventional multiplanar echocardiography was performed and necessary three-dimensional images were obtained to assess the underlying pathology. Then, three series of three-dimensional full-volume images oriented to the center of the LVOT were acquired during suspended breathing. Each series was obtained by acquisition of 4 cardiac cycles for off-line full-volume reconstruction. In the event of an alteration of normal sinus rhythm (generally, an isolated extrasystole), this series was rejected and a new one was acquired, until three series were obtained without gating faults. Image parameters were adjusted to obtain a sampling rate of 15-20 frames/second.

The analysis of the LVOT area was performed with QLAB 7.1 (Philips Ultrasound) software, in a working station separated from the equipment. Once the full-volume series were transferred to the working station, orthogonal sections of the LVOT were made, paying special attention they were made at 90° of its long axis. This was achieved using reference planes provided by QLAB (classically red and blue planes), yielding a LVOT short-axis in the third plane (green) (Figure 1).

The LVOT short axis was acquired 2-4 mm below the aortic valve annular plane. Three systolic and three diastolic phases were considered: proto-systole (S1): start of aortic valve opening; mid-systole (S2): maximum aortic valve opening; tele-systole (S3): start of aortic valve closure; proto-diastole (D1): start of mitral valve opening; mid-diastole (D2): partial AML closure during diastasis; and tele-diastole (D3): partial AML opening due to atrial systole.

As movement during the cardiac cycle produces misalignment of the cross-sectional plane, this was adjusted to achieve a short axis orthogonal to the long axis of the LVOT in each of the 6 phases. After the short-axis corresponding to each phase was acquired, the LVOT area was measured by planimetry and estimated in cm². An average of the three cycles was obtained for each phase.

The LVOT short-axis shape was assessed visually and by the major diameter/minor diameter relationship in protosystolic and protodiastolic phases.

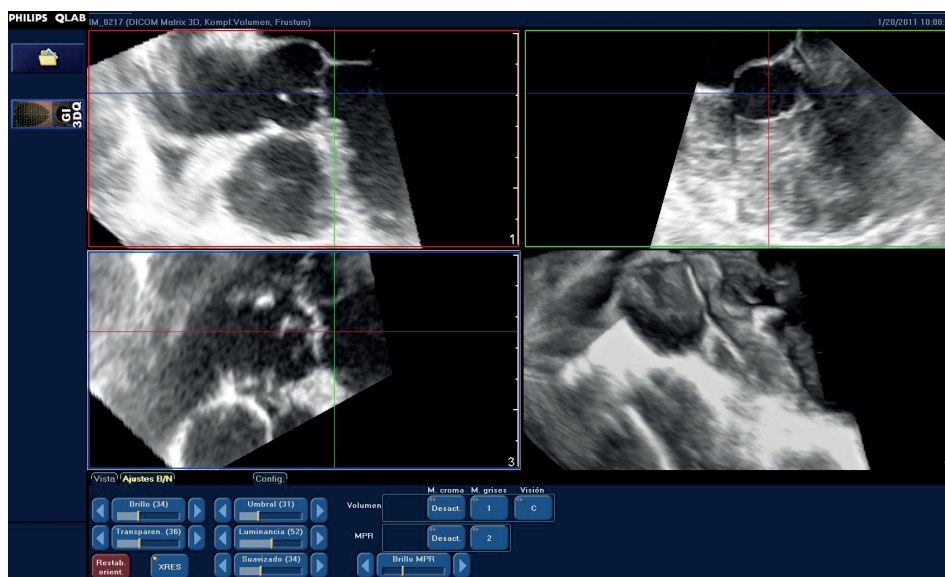


Fig. 1. Acquisition of LVOT orthogonal planes: LVOT long axis (red and blue planes) and its short axis orthogonal view (green plane). Measurement of major and minor diameters and the LVOT area are obtained by short axis planimetry from the green plane.

Values were expressed as mean $\pm$ standard deviation, median and ranges.

Maximum and minimum areas were compared, and in the same phases, major and minor LVOT diameters were measured. Comparison between areas and between diameters was performed using the non parametric Wilcoxon rank sum test for paired or dependent data, as these numerical variables did not comply with all the normal distribution assumptions.

The percent difference between maximum and minimum areas for each patient was used to assess percent area variation. The same procedure was adopted with major and minor diameters to assess percent diameter variation. The comparison of percent area and diameter variation was tested against the null hypothesis (variation = 0%) using the non-parametric Wilcoxon test.

RESULTS

Mean age was 67 ± 10 years. Patients were referred for investigation of embolic source (37%), assessment of valvulopathy (37%), suspicion of endocarditis (21%) or interatrial communication (5%). The remaining characteristics are detailed in Table 1.

Planimetric LVOT measurement was possible in 100% of cases. The LVOT shape and area were modified during the cardiac cycle (Figure 2). The largest LVOT area was observed during proto-systole, coincident with the scarce septal excursion towards the cavity and AML in the closed position. As systole progresses the septum protrudes towards the cavity and the LVOT area decreases. The smallest LVOT area was observed during proto-diastole, coincident with a certain septal persistence towards the cavity and AML opening. Then, with the displacement of the anterior leaflet to a partially closed (in mid-diastole) or partially opened (in tele-diastole) position, the area increases again reaching its maximum in the next proto-systole. The total LVOT area variation was statistically significant ($15\% \pm 11\%$; $p < 0.0001$). Similarly, the difference between proto-systolic and proto-diastolic areas was also significant ($p < 0.0001$) (Table 2, Figure 3).

Shape tended to be partially elliptical or circular in systolic phases and markedly elliptical or semilunar in diastolic phases, the latter mainly due to AML morphological and positional modifications in the LVOT: concave towards the LVOT in systolic phases

and flat or convex in diastolic phases (see Figure 2).

The major diameter in proto-systole was 2.46 ± 0.22 cm (median 2.38 cm) and the minor diameter 2.20 ± 0.25 cm (median 2.18 cm). The average proto-systolic major diameter / minor diameter relationship was 1.12 (a relationship = 1 indicates circular LVOT): Fifty percent of the patients had a major diameter / minor diameter relationship below 1.1, compatible with a predominantly circular shape (coincident with the visual estimation). The rest of the patients presented a partially elliptical shape with a maximum major diameter / minor diameter relationship of 1.34 in this phase.

The major diameter in proto-diastole was 2.46 ± 0.26 cm (median 2.40 cm) and the minor diameter 1.74 ± 0.28 cm (median 1.74 cm) with an average major diameter / minor diameter relationship of 1.44. Only one patient had a relationship below 1.1 (compatible with a circular shape); the rest of the patients presented elliptical or semilunar shapes according to the AML degree of protrusion during diastole (the maximum major diameter / minor diameter relationship was 2.29).

The greatest LVOT variation was due to modification of the minor diameter, mainly due to AML motion, with a difference between proto-systole and proto-diastole of 0.46 ± 0.19 cm, median 0.42 cm and $p < 0.0001$, and percent reduction of $21 \pm 9\%$, median 19% and $p < 0.0001$. On the other hand, the major diameter evidenced a scarce non-significant variation (0 ± 0.14 cm, median -0.03 cm and $p = 0.99$), with a percent reduction of $0 \pm 6\%$; median 1.3% and $p = 0.76$.

These findings indicate that the main contribution to LVOT area and shape variations is at the expense of the minor axis and seems to be more dependent on the mitral component (anterior leaflet) than on the interventricular septum.

DISCUSSION

Currently, LVOT area is estimated with two-dimensional imaging techniques, using the expression $\pi \times (D/2)^2$, where D is LVOT diameter measured in the mid-systolic long axis. (1) The introduction of new techniques for the treatment of valvulopathies, as percutaneous aortic valve replacement, demands detailed reports of LVOT and aortic root anatomy.

Table 1. Baseline population characteristics

Characteristics	Total = 42
Age, years	67 ± 10
Male gender, n (%)	26 (63)
Hypertension, n (%)	26 (63)
Dyslipidemia, n (%)	18 (43)
Diabetes, n (%)	5 (12)
Smoking, n (%)	2 (5)
Moderate or severe aortic stenosis, n (%)	7 (17)
Moderate or severe aortic insufficiency, n (%)	8 (19)
Moderate or severe mitral insufficiency, n (%)	10 (24)

Table 2. LVOT area variation during the cardiac cycle

Phase	Área (cm ²)		Range
	Mean $\pm$ SD	Median	
Proto-systole	4.44 ± 1.02	4,36	1,99-7,24
Mid-systole	4.15 ± 0.91	4,09	2,06-7,14
Tele-systole	3.90 ± 0.89	3,84	2,20-6,96
Proto-diasstole	3.76 ± 0.98	3,72	1,95-7,17
Mid-diastole	3.89 ± 1.04	3,70	2,13-7,2
Tele-diastole	4.34 ± 1.11	4,15	1,84-7,27

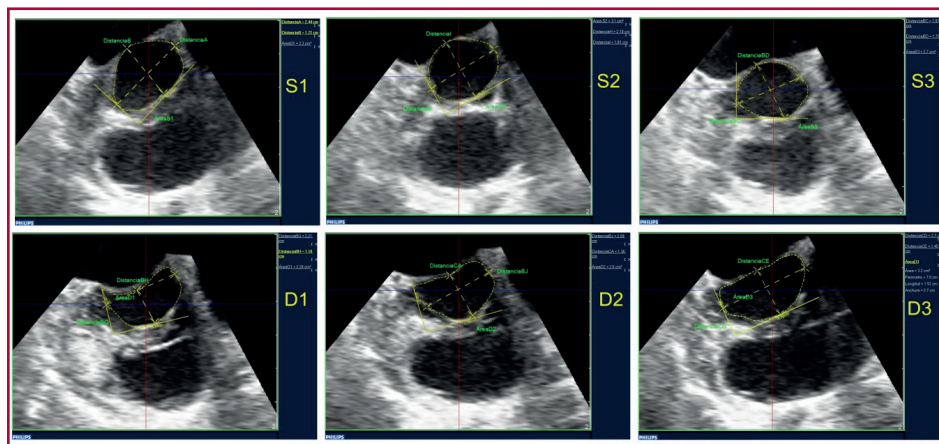


Fig. 2. LVOT planimetry in the different phases of the cardiac cycle (S1: proto-systole, S2: mid-systole, S3: tele-systole, D1: proto-diastole, D2: mid-diastole, D3: tele-diastole). In this case, a modification in the area and shape can be seen (partially elliptical in systolic phases, semilunar in diastolic phases).

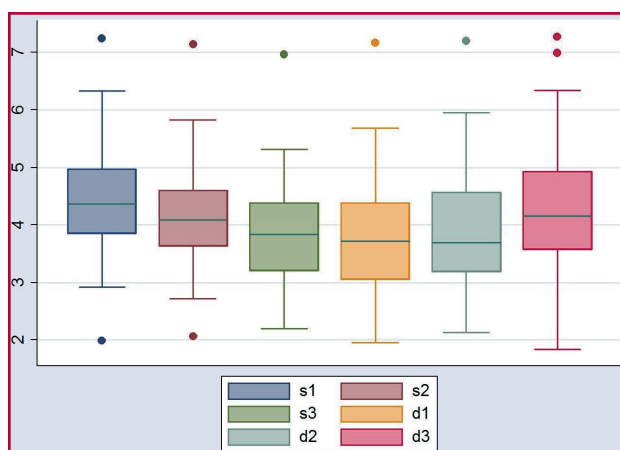


Fig. 3. LVOT area in the different phases of the cardiac cycle (S1 vs. D1: $p < 0.0001$). This box plot shows minimum measured values, lower quartile, median, upper quartile and maximum measured values, as well as outliers.

New three-dimensional imaging methods show that the normal LVOT anatomy is not circular in every case, as assumed with two-dimensional methods.

We may add that the two-dimensional section does not always go through the LVOT central axis, resulting in another source of potential error. (2)

Several studies have confirmed that the LVOT anatomy is more elliptical than circular, with a significant decrease of the LVOT area compared with that measured by planimetry. (3-6) This difference entails underestimation of the LVOT major and minor diameters, which are essential for the correct choice of percutaneous prosthesis, and increase of perivalvular leak risk and prosthesis migration, among other complications. (7)

In this study, we could verify the predominantly elliptical LVOT shape. We have also shown for the first time that this anatomical region changes substantially in shape and size during the cardiac cycle. Tops et al. assessed major and minor diameter modifications with multislice computed tomography (MSCT), verifying elliptical LVOT shapes. They also assessed diameter changes during tele-systole

and tele-diastole using a simple oblique sagittal view, which normally corresponds to the left parasternal long axis view (minor axis), and found no significant differences. (8) One of the deficiencies of this method is the low temporal resolution compared with 3D TE echo, with a frame rate not greater than 10-12 frames per second.

Although there is no reference method to evaluate the aortic root geometry, MSCT is generally used to assess the accuracy of 3D TE echo measurements. Otani et al, have demonstrated the good correlation between these two methods to assess the LVOT planimetric area ($r = 0.96$, mean difference: $0.35 \pm 0.29 \text{ cm}^2$). (5)

This method would also allow a modification of the continuity equation normally used to calculate AVA. There is general agreement that AVA measurement using the continuity equation overestimates the severity of aortic stenosis, (9-11) in part because the area is calculated and not measured directly, underestimating the component of the equation numerator. Using the planimetric LVOT area measurement, Burgstahler et al employed magnetic resonance to assess LVOT area by planimetry and AVA in normal and with moderate to severe stenosis populations. Results showed that using the modified continuity equation, the planimetric LVOT area gave the best correlation with the planimetric AVA measured by magnetic resonance. (4)

In medical databases, no studies are aimed to assess LVOT area modifications during the cardiac cycle. The present finding draws the attention on the interaction of new devices for percutaneous valve replacement. This is particularly important in our setting, where the only approved device relies mostly on the LVOT shape, whose modification during the cardiac cycle may influence its performance.

Limitations

One of the limitations of this study is the absence of a gold standard to measure LVOT area. Even though the correlation with MSCT is very good, the method has not been completely validated. Moreover, included patients were not consecutive, and the number of

patients with moderate and/or severe aortic stenosis was insufficient to compare with the total cohort. Neither was MSCCT performed to compare with 3D TE echo. Patients with structural cardiomyopathies that modify LVOT dynamics were excluded, precluding the extrapolation of results to these populations.

CONCLUSIONS

The LVOT area and shape is modified during the cardiac cycle, mostly at the expense of the minor axis due to AML motion and less to IVS excursion. 3D TE echo becomes a reliable alternative to assess LVOT anatomy and geometry.

RESUMEN

Dinámica del tracto de salida del ventrículo izquierdo durante el ciclo cardíaco evaluada con ecocardiografía tridimensional

Introducción

El tracto de salida del ventrículo izquierdo (TSVI) suele estar implicado con relativa frecuencia en alteraciones anatómicas y anatomofuncionales, que son objeto de estudios. Sin embargo, su dinámica normal también es importante, en particular en procedimientos que involucran su área, y los nuevos métodos de imágenes tridimensionales permiten evaluarla.

Objetivo

Evaluar la dinámica del TSVI durante el ciclo cardíaco por ecocardiografía tridimensional transesofágica (eco 3D TE).

Material y métodos

Se incluyeron en forma prospectiva 42 pacientes derivados para ecocardiografía transesofágica. Los estudios se realizaron con sonda transesofágica tridimensional, con adquisiciones de volumen completo integradas por 4 latidos gatillados para análisis off-line. El ciclo cardíaco se dividió en protosístole (S1), mesosístole (S2) y telesístole (S3) y en protodiástole (D1), mesodiástole (D2) y telediástole (D3). El área del TSVI se estimó por planimetría del eje corto por cortes ortogonales al eje mayor del TSVI en cada fase.

Resultados

La edad media fue de 67 ± 10 años; el 63% eran hombres. El área del TSVI (cm^2) en las diferentes fases del ciclo cardíaco fue: S1: $4,44 \pm 1,02$; S2: $4,15 \pm 0,91$; S3: $3,9 \pm 0,89$; D1: $3,76 \pm 0,98$; D2: $3,89 \pm 1,04$; D3: $4,34 \pm 1,11$. El área máxima se observó en S1, correspondiendo a la aposición de cierre de la valva anterior mitral (VaM) y escasa excursión del septum interventricular (SIV) hacia el TSVI; el área mínima se observó en D1 coincidiendo con cierta persistencia del SIV en el TSVI y la apertura máxima de la VaM ocupando parte del TSVI. La modificación total del área fue del $15\% \pm 11\%$ ($p < 0,0001$), cambiando además de forma parcialmente elíptica o circular (sístole) a marcadamente elíptica o semilunar (diástole).

Conclusión

El TSVI presenta una variación en su área y su forma durante el ciclo cardíaco, con dependencia fundamentalmente

del movimiento del SIV (en sístole) y de la apertura mitral (en diástole).

Palabras clave > Ventriculos cardíacos – Ecocardiografía tridimensional – Fisiología

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Conflict of interests

None declared.