Rev Bras Cardiol Invasiva. 2015;**23(2)**:130-133

Original Article

Differences between systolic and diastolic dimensions of the aortic valve annulus in computed tomography angiography in patients undergoing percutaneous implantation of aortic valve prosthesis by catheter

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ARTICLE INFO

Article history:
Received 19 January 2015
Accepted 8 March 2015

Keywords:
Transcatheter aortic valve replacement
Tomography, X-ray computed
Aortic valve stenosis

ABSTRACT

Background: Accurate aortic valve annulus sizing has critical importance for the planning of percutaneous transcatheter aortic valve implantation (TAVI) in patients with severe aortic valve stenosis. Although there is a recommendation to perform the measurement during systole, little is known about the importance of the differences between systolic and diastolic dimensions of the annulus.
Methods: Consecutive patients referred for TAVI were evaluated with computed tomography for valve annulus sizing during systole and diastole. Area, circumference, minimum and maximum diameters, and their mean derived diameters were obtained in both phases of the cardiac cycle. Bland-Altman plots were constructed to evaluate the differences between the measures.
Results: The analysis included 41 patients with severe aortic stenosis. Mean area, circumference, and diameters were slightly greater in systole. However, in 35% of patients, diastolic dimensions were greater. These differences, although statistically significant, were small (the greatest difference of 0.6 mm in mean diameter). Bland-Altman plots showed good agreement between systolic and diastolic measurements on all parameters evaluated.
Conclusions: Small differences were observed in the systolic and diastolic dimensions of the aortic valve annulus with computed tomography scan, which, although statistically significant, probably do not impact the selection of prosthesis or the procedure outcome.

Diferenças entre as dimensões sistólica e diastólica do anel valvar aórtico na angiotomografia computadorizada em pacientes submetidos a implante percutâneo de prótese valvar aórtica por cateter

Palavras-chave:
Substituição da valva aórtica transcateter
Tomografia computadorizada por raios X
Estenose da valva aórtica

RESUMO

Introdução: A medida acurada do tamanho do anel valvar aórtico tem importância fundamental para o planejamento do implante percutâneo de prótese valvar aórtica transcateter (TAVI) em pacientes com estenose valvar aórtica grave. Embora haja recomendação de se realizar a medida na sístole, pouco se sabe sobre a importância das diferenças entre as dimensões sistólica e diastólica do anel.
Métodos: Pacientes consecutivos referidos para TAVI foram avaliados com tomografia computadorizada para medida do anel valvar na sístole e na diástole. Área, circunferência, diâmetros máximo e mínimo, e seus diâmetros médios derivados foram obtidos em ambas as fases do ciclo cardíaco. Gráficos de Bland-Altman foram construídos para se avaliarem as diferenças entre as medidas.
Resultados: Foram incluídos na análise 41 pacientes com estenose aórtica grave. As médias da área, circunferência e diâmetros médios foram discretamente maiores na sístole. No entanto, em 35% dos pacientes, as dimensões diastólicas foram maiores. Essas diferenças, embora estatisticamente significantes, foram pequenas (a maior diferença de 0,6 mm no diâmetro médio). Gráficos de Bland-Altman revelaram bons níveis de concordância entre as medidas sistólicas e diastólicas em todos os parâmetros avaliados.

DOI of original article: http://dx.doi.org/10.1016/j.rbci.2015.12.012
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Peer Review under the responsability of Sociedade Brasileira de Hemodinâmica e Cardiologia Intervencionista.

Conclusões: Observamos pequenas diferenças nas dimensões sistólicas e diastólicas no anel valvar aórtico à tomografia computadorizada, as quais, embora estatisticamente significantes, provavelmente não impactam na seleção da prótese e nem no resultado do procedimento.

Introduction

Computed tomography angiography (CTA) is an important tool for anatomical assessment of patients with aortic valve stenosis who are candidates for percutaneous transcatheter aortic valve implantation (TAVI).[1] In many centers, CTA is considered the most important diagnostic method for planning intervention strategies for these patients. CTA has a particularly important role in valve annulus sizing, to guide the choice of the type and size of the prosthesis to be implanted.

Previous studies have demonstrated that aortic root dimensions may vary during the cardiac cycle.[2,3] These dimensional differences in systole and diastole are seemingly unpredictable, with systolic dimensions tending to be greater. However, the opposite can also occur.[2]

In daily clinical practice, CTA images are commonly acquired in a single phase of the cardiac cycle, often at the end of diastole, although an international expert consensus recommends that measures should be performed during systole.[1]

Although some studies have shown significant differences in systolic and diastolic measures, other groups suggest that these differences are minor, with little chance to change the decision making process.[2,4] However, there are few data in the literature to support recommendations with respect to the importance of these dynamic variations in the size of the aortic valve annulus to assess candidates for TAVI.

This study aimed to evaluate the differences in valve annulus size in systole and in diastole with CTA, and its potential effect on the planning of TAVI procedures.

Methods

Consecutive patients from two centers (Instituto do Coração, Hospital das Clínicas, University of São Paulo Medical School; and Hospital Sírio-Libanês) in the state of São Paulo (SP), with severe aortic valve stenosis (aortic valve area < 1 cm^2) considered inoperable or at high surgical risk, submitted to TAVI, and with CTA baseline images acquired both at the end of systole and of diastole were included in this analysis. All TAVI procedures were performed via transfemoral access with an Edwards Sapien XT balloon-expandable prosthesis (Edwards Lifesciences, Irvine, USA) or a Medtronic CoreValve auto-expandable prosthesis (Medtronic, Minneapolis, USA).

All scans were performed before (within 2 months) TAVI. Aquilion tomographs with 64- or 256-detector columns (Toshiba Medical Systems, Tokyo, Japan) were used, and the acquisition protocols were applied as previously described.[1] CTA image analysis was performed with the use of a dedicated workstation, as previously described, and by a single experienced analyst.[1] Briefly, the aortic valve plane was identified and the following valve annulus measurements were obtained in both systole and diastole: maximum (D_{max}) and minimum (D_{min}) diameter of the oval aortic valve annulus; mean diameter of the oval aortic valve annulus ($MD = [(D_{max} + D_{min})/2]$); planimetered area of the valve annulus (A); area-derived mean diameter, under the assumption of full roundness ($D_A = 2\sqrt{A/\pi}$); perimeter or circumference of the annulus (C); circle-derived mean diameter, under the assumption of full roundness ($D_C = C/\pi$).

Statistical analysis

Categorical variables were presented as absolute numbers and proportions. Continuous variables were presented as mean ± standard deviation and compared using the Student's paired t-test. Pearson correlation coefficients were used to correlate systolic and diastolic measures. The method proposed by Bland and Altman was used to assess differences in measurements of the aortic valve annulus in systole vs. diastole with CTA. In the Bland-Altman analysis, the difference between the two measures is plotted against their mean, with limits of 95% calculated to evaluate the correlation between these measures.[5,6]

Results

Study population

Between November 2012 and November 2014, 41 patients who underwent TAVI at 2 centers had a basal CTA with images at the end of systole and of diastole. The population characteristics are summarized in Table 1. In total, 48.8% of patients were female and were aged 83.5 ± 6.9 years. The mean logistic EuroSCORE was 13.7 ± 11.8%, and the mean Society of Thoracic Surgeons (STS) score was 19.2 ± 14.9%, reflecting a population at high surgical risk. Most (85.3%) were in functional class III or IV of the New York Heart Association (NYHA). At the baseline echocardiogram, the mean transvalvular gradient was 51.5 ± 17.4 mmHg and the mean aortic valve area was 0.7 ± 0.2 cm^2.

Table 1
Baseline characteristics.

	n = 41
Age, years	83.5 ± 6.9
Female, n (%)	20 (48.8)
STS score	19.2 ± 14.9
Logistic EuroSCORE	13.7 ± 11.8
Coronary artery disease, n (%)	22 (53.7)
NYHA functional class, n (%)	
I	1 (2.4)
II	5 (12.2)
III	24 (58.5)
IV	11 (26.8)
Previous AMI, n (%)	9 (22.0)
Previous coronary artery bypass graft surgery, n (%)	10 (24.4)
Previous PCI, n (%)	7 (17.1)
Previous aortic balloon valvuloplasty, n (%)	3 (7.3)
Cerebrovascular disease, n (%)	5 (12.2)
Peripheral arterial disease, n (%)	7 (17.1)
Creatinine > 2 mg/dL, n (%)	4 (9.8)
Severe COPD, n (%)	2 (4.9)
Hepatic cirrhosis (Child A or B), n (%)	1 (2.4)
Fragility, n (%)	6 (14.6)
Porcelain aorta, n (%)	1 (2.4)
Previous permanent pacemaker, n (%)	1 (2.4)
LV ejection fraction, %	57.3 ± 12.4
Mean aortic transvalvular gradient, mmHg	51.5 ± 17.4
Aortic valve area, cm^2	0.7 ± 0.2

STS: Society of Thoracic Surgeons; NYHA: New York Heart Association; AMI: acute myocardial infarction; PCI: percutaneous coronary intervention; COPD: chronic obstructive pulmonary disease; LV: left ventricle.

Aortic valve annulus dimensions

A good linear correlation was observed in systolic and diastolic measures of oval aortic valve annulus-derived maximum, minimum, and mean diameters; of the planimetered area of the valve annulus; of the mean diameter of the area, under the assumption of full roundness; of the circumference of the annulus and of the circumference-derived mean diameter, under the assumption of full roundness (Table 2, Figs. 1-3).

The circumference-derived mean diameters were greater, both in diastole and in systole, when compared to oval aortic valve annulus--derived mean diameters or to area-derived mean diameters, under the assumption of full roundness (Table 3).

Except for maximum diameter, all measures of the aortic valve annulus were higher in systole, with statistical significance (Table 4). However, the differences between systolic and diastolic measures were small, with the largest difference found for the mean diameter of the annulus (0.6 ± 1.2 mm; 95% confidence interval - 95%CI = 0.2–1.0; $p = 0.004$). Furthermore, when considering the measurements of all 41 patients, 14 (35%) had at least one diastolic measurement greater than its corresponding systolic measurement. This finding contributes to small, although statistically significant, differences among mean measurements.

The Bland-Altman plots showed good agreement between systolic and diastolic measurements, with approximately ± 2 mm difference between them (Figs. 4-6).

Table 2
Correlation between systolic and diastolic dimensions of the aortic valve annulus in computed tomography angiography.

Parameter	Pearson correlation coefficient	*p*-value
Maximum diameter of the annulus	0.77	< 0.001
Minimum diameter of the annulus	0.76	< 0.001
Area of the annulus	0.83	< 0.001
Circumference of the annulus	0.83	< 0.001
Mean annulus ring diameter[a]	0.82	< 0.001
Area-derived mean diameter[b]	0.82	< 0.001
Circunference-derived mean diameter[c]	0.83	< 0.001

[a] MD = $[(D_{max} + D_{min})/2]$; [B] $D_A = 2\sqrt{A}/\pi$; [c] $D_C = C/\pi$.

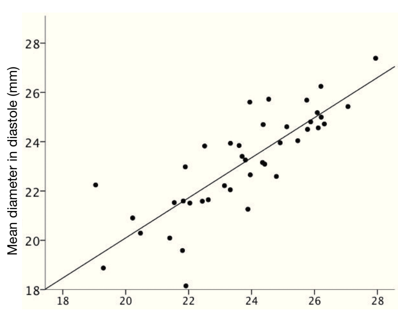

Figure 1. Correlation between systolic and diastolic dimensions of the mean diameter of the aortic valve annulus derived from maximum and minimum diameters.

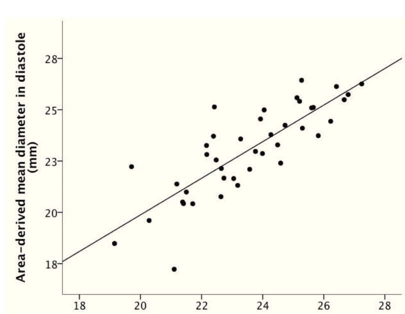

Figure 2. Correlation between systolic and diastolic dimensions of the mean diameter derived from the area of the aortic valve annulus.

Table 3
Measurements of aortic valve annulus with computed tomography angiography.

Parameter	Systole	Diastole
Maximum diameter of the annulus, mm	26.4 ± 2.4	26.2 ± 2.4
Minimum diameter of the annulus, mm	21.0 ± 2.3	20.0 ± 2.3
Area of the annulus, cm^2	43.8 ± 7.4	42.0 ± 7.7
Circumference, mm	75.9 ± 6.3	74.7 ± 6.8
Mean diameter[a], mm	23.7 ± 2.1	23.1 ± 2.1
Area-derived mean diameter[b], mm	23.5 ± 2.0	23.0 ± 2.2
Circumference-derived mean diameter[c], mm	24.2 ± 2.0	23.8 ± 2.2

[a] MD = $[(D_{max} + D_{min})/2]$; [b] $D_A = 2\sqrt{A}/\pi$; [c] $D_C = C/\pi$.

Table 4
Differences in the dimensions of the aortic valve annulus between systole and diastole.

Parameter (mm)	Mean difference ± SD (95%CI)	*p*-value
Maximum diameter, mm	0.2 ± 1.6 (-0.3–0.7)	0.44
Minimum diameter, mm	1.0 ± 1.6 (0.5–1.5)	< 0.001
Area, cm^2	1.8 ± 4.5 (0.4–3.2)	0.01
Circumference, mm	1.2 ± 3.9 (-0.02–2.4)	0.05
Mean diameter,[a] mm	0.6 ± 1.2 (0.2–1.0)	0.004
Area-derived mean diameter,[b] mm	0.5 ± 1.3 (0.1–0.9)	0.01
Circumference-derived mean diameter,[c] mm	0.4 ± 1.2 (-0.01–0.8)	0.05

[a] MD = $[(D_{max} + D_{min})/2]$; [b] $D_A = 2\sqrt{A}/\pi$; [c] $D_C = C/\pi$.

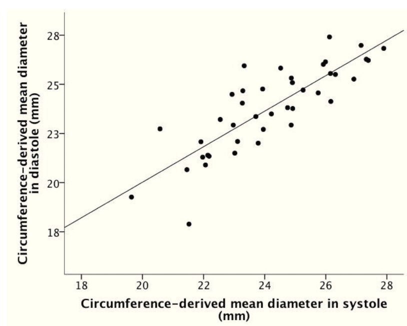

Figure 3. Correlation between systolic and diastolic dimensions of the mean diameter derived from the circumference of the aortic valve annulus.

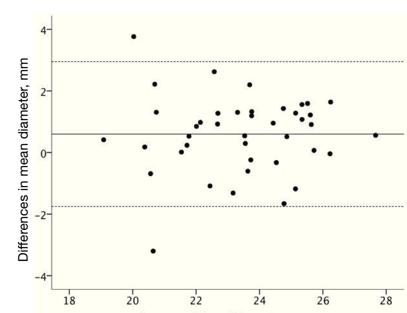

Figure 4. Bland-Altman plot to assess the differences between the systolic and diastolic dimensions of the mean diameters.

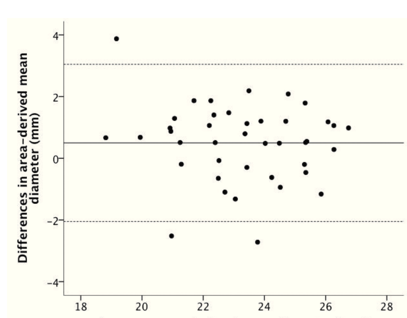

Figure 5. Bland-Altman plot to assess the differences between systolic and diastolic dimensions of mean diameters derived from the area.

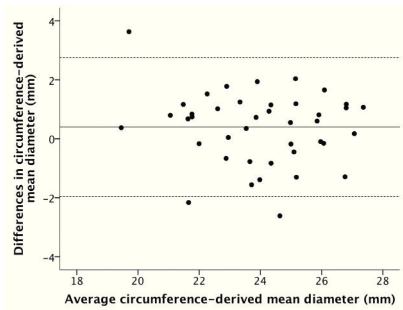

Figure 6. Bland-Altman plot to assess the differences between systolic and diastolic dimensions of mean diameters derived from the circumference.

Discussion

The main finding was that in patients with severe aortic stenosis undergoing TAVI, there are small differences, although statistically significant, in systolic and diastolic dimensions of the aortic valve annulus, when evaluated by CT angiography with the use of various measures, such as area, circumference, and diameters. The data showed that, despite these differences, there is good agreement between measurements in both phases of the cardiac cycle.

Strictly accurate measurement of the aortic valve annulus is of critical importance in planning TAVI, since oversizing can lead to an usually fatal aortic rupture, while undersizing can cause periprosthetic regurgitation, which is associated with a subsequent worse prognosis.[7]

CT angiography is currently considered the most accurate method for measuring the size of the aortic valve annulus. However, the literature is scarce with respect to the importance of variations in the dimensions of the aortic valve annulus during the cardiac cycle. While some experts recommend that measures are conducted in systole, many centers acquire single-phase images at the end of diastole, since coronary images are often jointly obtained.[1] In this context, the real importance of choosing a specific phase of the cardiac cycle for the measurement of the aortic valve annulus is not yet known.

In patients without aortic root disease, there is significant individual dynamic variation in their dimensions (± 5 mm). These variations are independent of clinical variables such as age, gender, height and weight, and are quite unpredictable.[2] Although the presence of calcium does not appear to modify these dynamic changes, in patients with severe aortic valvular stenosis the variability appears to occur to a lesser extent.[3,4]

The present study also found variability in the cardiac cycle with respect to the dimensions of the aortic valve annulus, which occurred on a scale of approximately ± 2 mm. This variability also appears to be very unpredictable, since in 35% of these patients, at least one parameter was higher in diastole than systole, although the mean systolic measures obtained were higher than the mean diastolic measures for all parameters studied. This may explain the small differences in mean measures, with negative differences canceling the positive ones. In fact, the highest mean difference observed was 0.6 mm for the oval aortic valve annulus mean diameter, which is unlikely to have an impact on the prosthesis selection or on the procedure outcome.

Limits of agreement between two different measures are actually arbitrarily defined.[5] It might be argued that a 2-mm difference between the measures of the aortic valve annulus constitutes an unacceptably high difference. There are cases in which an even greater difference was found. However, in the present data, as shown on Bland-Altman plots, approximately 95% of this population fall between these limits. It is possible that in some cases there will be a greater difference, which may influence the selection of the prosthesis and the outcome of the procedure. Unfortunately, no means to predict such cases could be determined.

Study limitations

This was a small sample size study, involving only two centers. As there was only one image analyst, interobserver variability could not be assessed. Considering that several parameters (area, circumference, and diameters) have demonstrated different interobserver variability rates in the literature, this may have influenced the results.

Conclusions

Although there were statistically significant differences between systolic and diastolic measures of the aortic valve annulus, these were minor and with good agreement between measurements in the various parameters evaluated. Thus, it is unlikely that the choice of the measure for the aortic valve annulus dimension during systole and diastole has a significant impact on the selection of prosthesis, as well as on the outcome of the procedure.

Funding source

None.

Conflicts of interest

The authors declare no conflicts of interest.

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