

RESEARCH

Preoperative aortic annulus size assessment by transthoracic echocardiography compared to the size of surgically implanted aortic prostheses

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Abstract

Objectives: The aortic annulus diameter measured by transthoracic echocardiography yields lower values than by computed tomography, and echo-based selection of transcatheter aortic valve prosthesis size has been implied to result in more frequent paravalvular leakage. We investigated the relation of preoperative annulus diameter by echo with the ring size of the aortic prosthesis chosen by direct assessment during open-heart aortic valve replacement.

Methods: Preoperative annulus diameter by echo (from parasternal long-axis cross-sections of the left ventricular outflow tract and aortic valve) and implanted prosthetic diameter (tissue annulus diameter, determined intraoperatively using a sizing instrument) were compared retrospectively in 285 consecutive patients undergoing open-heart aortic valve replacement.

Results: A total of 285 prostheses (240 biologic and 45 mechanical) were implanted, with prosthetic diameter ranging between 19 and 27 mm. There was a significant linear correlation ($P < 0.0001$) with $r = 0.51$, between preoperative annulus diameter by echo (mean 21.8 ± 2.8 mm) and prosthetic diameter (22.9 ± 1.7 mm). Preoperative annulus diameter of patients receiving prostheses no. 21, 23 and 25 mm aortic prostheses (the most frequent prosthesis sizes) were significantly different ($P < 0.001$) from each other. On average, preoperative annulus diameter by echo underestimated prosthetic diameter by a bias of 1.07 mm.

Conclusion: Our data confirm that preoperative echo assessment of the aortic valve may slightly underestimate the optimal surgical prosthesis diameter for the aortic valve annulus.

Key Words

- ▶ aortic valve
- ▶ aortic valve replacement
- ▶ prosthetic valve
- ▶ echocardiography

Introduction

The aortic annulus is a virtual ring at the base of the aortic root. The level of the aortic annulus is defined by the three nadirs (lowest points in the direction of the left ventricular outflow tract) of the U-shaped attachments of each aortic cusp (1). Direct intraoperative sizing during open-heart

surgery may be regarded as the empirical standard for aortic annular measurement (2), although sizer dimensions have been reported to differ slightly from actual precision measurements (3). During surgical aortic valve replacement (AVR), sizing using a dedicated instrument (Fig. 1) is

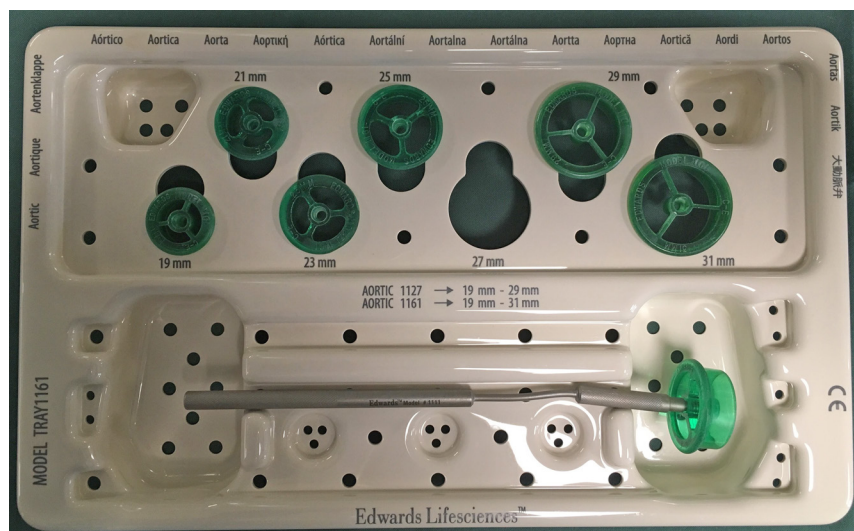


Figure 1
Sizing instrument (Edwards Lifesciences aortic sizers tray for Perimount Magna Ease valves by Carpentier-Edwards) used for choice of prosthesis during surgical aortic valve replacement.

performed prior to implantation during cardiac standstill, and the appropriate size of the prosthetic valve is selected according to the result of this procedure. Therefore, preoperative determination of aortic annular size is of limited importance in this setting. This is different with transcatheter aortic valve implantation or replacement, a ‘closed heart’ procedure where direct measurement of the aortic annulus is unobtainable and the size of the prosthetic valve mounted on the delivery catheter must be chosen in advance. Aortic annulus dimensions must therefore be assessed by noninvasive means, for example transthoracic echocardiography (TTE), gated computer tomography (CT) or transesophageal echocardiography (TEE).

Aortic annulus diameter by TTE (AAecho) yields systematically lower values than TEE or CT. In addition, the oval shape of the aortic annulus, with a major dimension approximately orthogonal to the antero-posterior diameter classically measured by TTE contributes to underestimation of aortic annulus area when CT or 3D-TEE-based data are compared to area calculated from TTE assuming a circular annulus shape. These discrepancies have been implied to lead to more paravalvular leaks after TAVI if size of TAVI prostheses is selected on the basis on AAecho measurements (4, 5). Thus, the general reliability of TTE measurements of the aortic annulus has been called into question. We therefore compared TTE to direct intraoperative surgical sizing during open-heart aortic valve surgery.

Patients, materials and methods

All adult patients who underwent AVR for aortic valve disease due to aortic stenosis or regurgitation during two years at our institution were retrospectively analyzed.

All study data were extracted from clinically indicated preoperative examinations. The aortic annulus diameter measurement in the routine preoperative transthoracic echocardiographic examination (AAecho) was obtained from parasternal long-axis cross-sections of the left ventricular outflow tract and aortic valve (Fig. 2), wherever possible from zoomed images. The diameter was measured inner-edge to inner-edge, in midsystole, from the hinge point of the right coronary aortic cusp orthogonal to the direction of flow, toward the commissure of left and non-coronary cusp, as recommended in echocardiographic guidelines (6). If present, outflow tract calcifications were included in the diameter. All measurements were carried out by re-analyzing digitally stored images by the same physician who was unaware of the size of

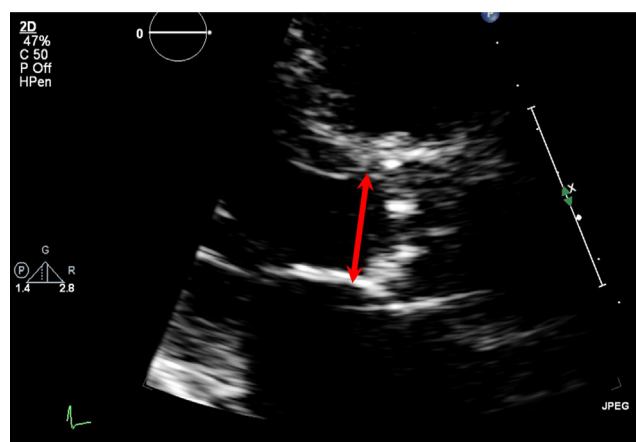


Figure 2
Preoperative aortic annulus diameter measurement by echocardiography (20 mm). Magnification of a parasternal long-axis view in systole. Note inclusion of small calcification of the posterior border of the left ventricular outflow tract in the diameter.

the implanted prosthesis. Linear transthoracic echocardiographic measurements, including aortic annular diameter, have a coefficient of variation of $8 \pm 6\%$ in our laboratory. Intraoperatively, the aortic annulus diameter (tissue annulus diameter, AAsurg) was identified using a sizing instrument to routinely determine the optimal aortic valve prosthesis size by directly probing the aortic root after excision of the native valve. First, the native calcified aortic leaflets, including possible calcification of the aortic annulus, were excised and then the size of the prosthesis was determined as the biggest dilator that could be fitted in to the aortic annulus.

The following exclusions were made: three patients underwent a repair operation and did not receive a prosthetic valve. One patient had too extensive calcification of the left ventricular outflow tract to obtain measure AAecho with confidence. Fourteen only had a transesophageal preoperative echo. Eleven were left out due to missing or bad quality TTE images of the left ventricular outflow tract and aortic valve. Eleven patients had a preoperative TTE exceeding 8 months before the valve operation. Four only had a peroperative echo and one patient had missing echo data. The study was approved by the Local Ethical Committee (Etikprövningsnämnden Uppsala, Nr. 2016/224). Written informed consent has been obtained from each patient after full explanation of the purpose and nature of all procedures used. Statistical analysis was conducted using Microsoft Excel, analyzing data with linear correlation and *t*-tests for unpaired samples. Data are given as mean \pm standard deviation, unless stated otherwise.

Results

The study population consisted of 285 patients (age range 23–88 years) in whom AAecho and AAsurg were compared (Table 1). The average time interval between echo and operation for the patients included in the study was 3.8 months, range (0–16.8 months). A total of 240 biologic prostheses and 45 mechanical prostheses) were implanted, with an AAsurg ranging between 19 and 27 mm. AAecho ranged between 16 and 32 mm. The distribution of prosthesis sizes is shown in Fig. 3 and Table 1. There was a significant linear correlation ($r=0.51$; $P<0.0001$; $AAsurg=0.84 Aaecho+2.51$) between AAecho (mean 21.8 ± 2.8 mm) and AAsurg (22.9 ± 1.7 mm). AAecho of patients receiving prostheses no. 21, 23 and 25 mm aortic prostheses (the most frequent prosthesis sizes used) were significantly different ($P<0.001$) from each other (Fig. 4). On average, AAecho underestimated

Table 1 Demographic data of the study cohort.

Demographic data	
Age	70 \pm 10.8
Body surface area (BSA)	1.96 \pm 0.2
Males/females	188/97
Biologic/mechanic valve prosthesis	240/45
Primary reason for operation	Aortic stenosis (264), aortic regurgitation (18), other (3)
Valve size average	22.85 \pm 1.70
Number of patients with different prosthesis sizes	
Valve size 19	8
Valve size 20	4
Valve size 21	74
Valve size 22	3
Valve size 23	125
Valve size 24	6
Valve size 25	56
Valve size 26	1
Valve size 27	8

AAsurg by a bias of 1.07 mm with limits of agreement of ± 4.8 mm (Fig. 5). There was no significant difference in underestimation between patients operated for aortic stenosis and the small group operated for other reasons, mainly aortic regurgitation.

Discussion

In this retrospective analysis, we found a weak but significant correlation, considerable scatter and a small but significant bias when comparing preoperative echocardiographic and intraoperative direct measurements of aortic annulus size in a large, real-life, consecutive cohort of adult patients undergoing surgical AVR. Our results confirm the finding by other authors that echocardiography systematically underestimates aortic annulus diameter compared to CT or magnetic resonance imaging. However, the bias was small (1.07 mm). While our standard, intraoperative surgical

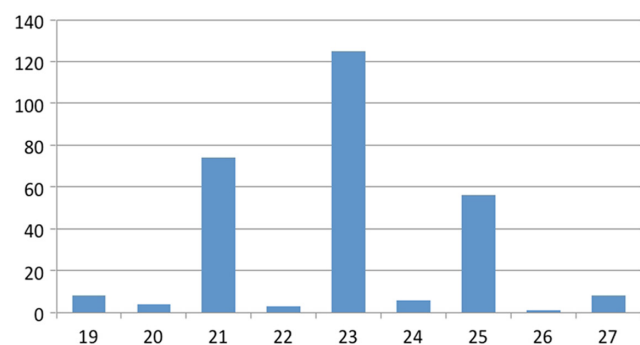


Figure 3 Distribution (histogram) of aortic prosthesis sizes. Prosthesis size on the x-axis and number of cases on the y-axis.

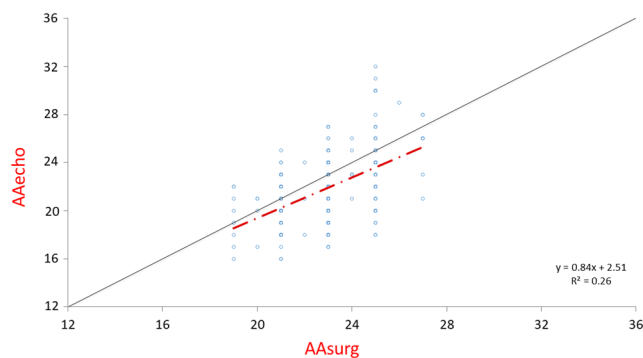


Figure 4
Scatterplot of echocardiographically measured annulus diameter AAecho (y-axis) and surgically determined diameter AAsurg (x-axis). The black continuous line is the line of identity, and the broken thin red line is the linear regression line. The regression equation and variance (R^2) are also given.

sizing, can be questioned (3), it is as close to the real anatomy as conceivably possible and the surgical standard to choose intraoperatively the size of aortic valve prostheses.

Several factors may contribute to this underestimation. Echocardiography tends to generate slightly lower linear, area and volume measurements than CT or magnetic resonance imaging; this is well known for example for cardiac chamber volumes (7, 8). This is related to the depiction of the tissue–blood interface, which originally led to the recommendation to use the leading-edge to leading-edge convention for linear measurements (9). We measured, as recommended by current guidelines, the aortic annular diameter inner-edge to inner-edge, from the insertion point of the right coronary cusp orthogonal to the direction of flow, toward the commissure of left and non-coronary cusp, including calcifications, where present, in the diameter. Another important factor is the possibility of tangentially positioning the long-axis cross-section through the aortic root and left ventricular outflow tract, thus missing the true diameter. Such geometric errors cannot entirely be avoided while

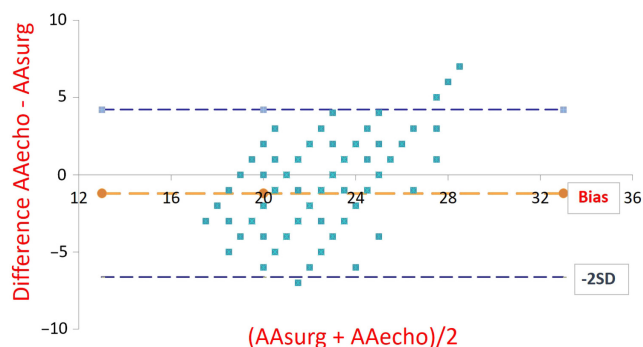


Figure 5
Bland–Altman plot. AAecho underestimates AAsurg by a bias of 1.07 mm.

using two-dimensional methodology, although during acquisition the maximal diameter of the root and outflow tract should be systematically sought. Finally, the aortic annulus often has a slightly elliptical shape, with the antero-posterior diameter being the minor axis, thus underestimating the true annular area if circular geometry is assumed. In addition to these drawbacks, image quality by echocardiography is variable, which is why our cohort of consecutive patients may give a realistic estimate of the accuracy achieved in routine echocardiography.

Several other studies have addressed this issue. In the earliest, Wiseth *et al.* (10), studied 34 patients and found a strong correlation between 2D echo measurements and intraoperative sizing ($r=0.88$), with small underestimation by TTE (limits of agreement, -0.9 to -2.0 mm). A second group of 24 patients receiving a supraannular prosthesis showed weaker agreement (10). A more recent study analyzed the relation between TEE, CT, and intraoperative measurements in 33 patients with aortic stenosis (11). CT measurements were derived from planimetry of the aortic annulus, conversion of the planimetered area to a circle and calculation of diameter from this circle. CT diameter values were slightly larger and correlated better with intraoperative measurements than TEE. Another relatively small study studied TTE, TEE, CT and intraoperative sizing in 26 patients undergoing aortic valve surgery (12). Surprisingly, this study found a very high correlation ($r=0.85$) and a (non-significant) mean difference between AAecho and AAsurg of only 0.38 mm (limits of agreement, -3.28 to 4.03 mm). Nevertheless, CT correlated even better, with narrower limits of agreement (-3.16 to 2.05 mm) and slight overestimation of intraoperative values.

Another recent, larger study compared TEE and CT derived aortic annulus size in 227 patients (2). The researchers found underestimation of surgical measurements by TEE and, surprisingly, overestimation by CT, suggesting that both methods should be combined to arrive at an adequate prediction of aortic annulus diameter.

For the purpose of surgical AVR, the conflicting results of different imaging modalities rarely matter, since sizing can be performed intraoperatively. For transcatheter aortic valve implantation/replacement, the discrepancies have led to abandonment of TTE measurements and mostly reliance on pre-interventional CT, which usually is performed anyway to assess the arterial vasculature. However, the validity of the nomograms used to select transcatheter valve size can be questioned and implantation involves deliberate and variable ‘oversizing’.

Nevertheless, the question whether TTE is grossly inaccurate in measuring aortic annular diameters is

important in the context of aortic valve and aortic root disease or with regard to stroke volume calculations, which are also implicit in calculations of aortic valve area by continuity or in quantitative Doppler assessment of valvular regurgitation. In this regard, although the bias of approximately 5% of the measurement is small, large scatter is evident from our data (limits of agreement, ± 4.8 mm), confirming limited accuracy of this measurement. Given these limitations of standard transthoracic echocardiographic measurement of the outflow tract diameter, one may wonder if it should not be abandoned altogether in favor of 3D transoesophageal, or, more likely, cardiac computed tomography measurements. However, standard echocardiography remains the first and, in the majority of cases, the only necessary imaging modality in the assessment of aortic valve disease. Clearly, however, for specialized questions such as sizing of implantable valve prostheses or evaluation before and during aortic valve repair, the above mentioned methods are preferable.

Conclusion

Our data, from a large real-world cohort of consecutive patients confirm that AAecho assessment of the aortic valve slightly (by 1.1 mm) underestimates the optimal prosthesis size for the aortic valve annulus.

Declaration of interest

Frank Flachskampf is an Associate Editor of *Echo Research and Practice*. He was not involved in the review or editorial process for this paper, on which he is listed as an author. The other authors have nothing to disclose.

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