FEASIBILITY OF AORTIC DIAMETER MEASUREMENT BY MULTIPLANE TRANSESOPHAGEAL ECHOCARDIOGRAPHY FOR PREOPERATIVE SELECTION AND PREPARATION OF HOMOGRAFT AORTIC VALVES

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Background: Preoperative knowledge of the aortic annular diameter could enable the preoperative selection and preparation of an appropriately sized homograft aortic valve. **Objective:** The aims of this study were to prospectively determine whether the combined use of transthoracic and multiplane transesophageal echocardiography allows accurate preoperative aortic annular measurements for the selection and preparation of adequately sized homograft aortic valves and to retrospectively evaluate the influence of the echocardiographic approach (transthoracic vs transesophageal) and the reader's level of experience on the accuracy of these measurements. **Methods:** Aortic annular measurements were performed before the operation by an experienced reader who used a combination of transthoracic and multiplane transesophageal images of 25 patients (mean age 52 ± 13 years) referred for homograft aortic valve replacement. Measurements were also performed retrospectively by three additional readers with different levels of training in echocardiography. These readers acquired aortic annular diameters from prerecorded tapes and obtained measurements from each echocardiographic modality independently. All values were compared with the surgical measurement obtained with a ring valve sizer. **Results:** With the combined echocardiographic approach, excellent agreement was found between preoperative echocardiographic and surgical measurements (mean difference ± 2 standard deviations = 0.2 ± 1.4 mm). All echocardiographic data were found to be within 2 mm of the surgical measurement. These measurements were used to select and prepare the aortic homograft valve before insertion. The accuracy of annular measurements appeared to increase in parallel to the level of experience. The aortic annular measurements obtained retrospectively by a second experienced reader were more accurate with the use of transesophageal than with transthoracic echocardiography ($p < 0.01$). In contrast, the echocardiographic modality had no influence on the accuracy of measurements of less experienced readers ($p > 0.2$). **Conclusions:** Preoperative measurement of the aortic annular diameter by transthoracic and multiplane transesophageal echocardiography is accurate and clinically feasible. Preoperative knowledge of the aortic annular diameter may be used to select and prepare the aortic homograft, improving valve availability and reducing ischemic time. (J Thorac Cardiovasc Surg 1996;112:954-61)

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Cryopreserved homograft aortic valves are associated with low reoperation and morbidity rates,¹ do not require anticoagulation, and have excellent hemodynamic profiles in conjunction with proven durability.^{2,3}

The selection of an appropriately sized homograft aortic valve is performed during the operation with a ring valve sizer while the patient is supported by cardiopulmonary bypass with the aorta cross-clamped. After the aortic annular diameter has been measured, an appropriately sized homograft valve is selected, thawed, trimmed, and prepared for im-

plantation. This procedure usually adds 20 to 30 minutes of bypass time to the surgical intervention.⁴

Preoperative knowledge of the aortic annular diameter would enable preoperative selection and preparation of an adequately sized homograft valve and shorten surgical ischemic time.⁴ The availability of an appropriately sized aortic homograft valve would be ensured, thereby circumventing current inventory limitations. Complex aortic valve and root operations, such as placement of composite grafts, could also be planned in advance.

The purpose of this study was to prospectively use combined transthoracic (TTE) and transesophageal (TEE) echocardiography to provide the surgeons with preoperative aortic annular measurements for the selection and preparation of aortic homografts and to retrospectively evaluate which echocardiographic modality, TTE or TEE, provides more detailed anatomic data for measuring the aortic annular diameter. We also studied the influence of the readers' experience on the accuracy of these measurements. In both sections of this study, the echocardiographically derived annular measurements were compared with the annular size, which was determined during the operation with the use of a ring valve sizer.

Methods

Patients. During a 3-year period, 25 patients (21 men) referred for elective or emergency aortic valve replacement with aortic homograft valves were studied. Patients' ages ranged from 26 to 72 years, with a mean age of 52 ± 13 years. Nine patients had predominant aortic stenosis, attributed to bicuspid valves in four, degenerative sclerocalcific cuspal changes in three, rheumatic disease in one, and congenital disease in one. Twelve patients had predominant aortic insufficiency, a consequence of a bicuspid aortic valve in four, Marfan's disease in two, infective endocarditis in three, and miscellaneous causes in three. The four remaining patients had mixed aortic valve disease caused by bicuspid aortic valves.

Study design. Within 1 week of the scheduled surgical procedure, all patients underwent TTE and TEE with the use of a commercially available ultrasound cardiac system (Hewlett-Packard Sonos 1500, Hewlett-Packard Company, Andover, Mass.). A 2.5 MHz transducer and 5 MHz multiplane transducer were used to acquire TTE and TEE images, respectively, and echocardiographic studies in both approaches were recorded on videotape for subsequent measurements.

Our main goal was to provide the cardiac surgeon with an aortic annular measurement for the preoperative selection and preparation of the appropriately sized aortic homograft valve. An experienced reader with previous training in echocardiographically determined annular measurements used TTE and multiplane TTE images to

measure the size of the aortic anulus. This diameter was then compared with the one measured during the cardiac operation by a ring valve sizer.

In the second part of this study, the influence of echocardiographic modalities (TTE and TEE) and the level of experience of the readers on the accuracy of aortic annular measurements were retrospectively evaluated. Aortic annular diameters were measured from the prerecorded videotapes by three additional readers with different levels of experience in ultrasound interpretation (experienced: 10 years; intermediate: 3 years; inexperienced: 6 months). These readers measured aortic annular diameters obtained from each modality independently. TEE measurements of the aortic anulus obtained by both experienced readers were used to calculate the interobserver variability. To evaluate the intraobserver variability of these measurements, one of the experienced readers measured the aortic anulus twice, with a 3-week interval between measurements. All echocardiographically measured aortic anulus diameters were compared with the measurements obtained at the time of operation.

Aortic annular diameter measurements. So that data acquisition for annular measurements with TTE and TEE would be optimal, the ascending aortic root was aligned in a longitudinal orthogonal axis (parasternal view on TTE), with the right and noncoronary sinuses symmetrically oriented to either side of the aortic root. So that the precise leaflet insertion site into the aortic anulus would be better delineated and identified, scanning from the short to the long axis was frequently performed.

The aortic annular diameter was measured at the time of maximal aortic leaflet excursion as the maximal distance separating the bases of the noncoronary and right coronary cusps or, in the case of bicuspid valves, anterior and posterior leaflets. The longitudinal aortic images were frozen in early systole, and electronic calipers were placed at the vertex of the angles formed by the aortic root and coronary cusps to obtain the annular diameters (Fig. 1). These measurements were initially obtained in triplicate, and the values were averaged only if the intermeasurement variability was less than 1 mm. If the variability was greater than 1 mm, measurements were repeated until consistency was achieved.

Statistical analysis. To determine the accuracy of aortic annular echocardiographic measurements, combined TTE and TEE values (prospective study) and the independently acquired TTE and TEE values (retrospective study) were compared with intraoperative measurements by the method of Bland and Altman.⁵ According to this method, individual differences between the echocardiographic measurements and surgical values were plotted against the surgical values. When a normal distribution is assumed, 95% of the differences lie between the mean $\pm$ 2 standard deviations. Student's *t* test was used for the interobserver and intertechnique comparison of these mean differences.

Interobserver variability of TEE measurements is expressed as the percent difference between the two measurements, divided by the mean annular value obtained by both observers. Similarly, intraobserver variability is expressed as

Fig. 1. TEE still frame obtained with a multiplane probe (longitudinal plane) from a patient with a normal trileaflet aortic valve. It demonstrates proper alignment of the aortic root and sinuses of Valsalva. Arrows depict placement of calipers for correct aortic annular measurement. The measurement was obtained in early systole, at the time of maximal leaflet excursion. LA, Left atrium; LV, left ventricle; RV, right ventricle; NCC, noncoronary aortic cusp; RCC, right coronary aortic cusp.

the percent difference between the two successive annular determinations, divided by the mean annular diameter value.

Results

The prospective annular measurements obtained by the experienced reader with a combined TTE and TEE approach resulted in accurate preoperative prediction of the aortic annular size (Fig. 2). The mean difference between echocardiographic and surgical measurements was 0.2 ± 0.7 mm (mean $\pm$ standard deviation). With this approach, all measurements were within 2 mm of the surgical values. In only two cases (8%), the discrepancy between TTE and TEE measurements obtained by the experienced reader exceeded 1 mm. In these cases, the TEE measurements were provided to the surgeon. As a consequence, inventory limitations were circumvented, and preoperative selection and preparation of adequately sized aortic homografts were possible.

In the retrospective study, only the experienced reader obtained more accurate annular measurements with TEE than with TTE ($p < 0.01$; Fig. 3). In contrast, the accuracy of aortic annular measurements obtained by the intermediate and inexperi-

enced readers (Figs. 4 and 5) was not influenced by the echocardiographic approach ($p > 0.2$). The limits of agreement between preoperative TTE and TEE aortic annular measurements and those obtained at the time of operation decreased with the reader's level of experience (see Figs. 3 through 5). For the experienced reader, a small positive bias was observed for both echocardiographic approaches (see Fig. 3). Accuracy of echocardiographic measurements at all levels of experience did not appear to be affected by aortic annular size or underlying aortic disease. The interobserver and intraobserver variabilities of TEE measurements of the aortic annulus were 4.6% and 2.8%, respectively.

Several examples from patients in this study demonstrate common pitfalls encountered during echocardiographic determination of the aortic annular size. The first example (Fig. 6) was obtained from a patient in whom the diagnosis was aortic insufficiency. After completion of the TTE examination, the cause of this valvulopathy remained unclear. Technical limitations impeded adequate visualization of the leaflet insertion sites to the aortic annulus. Improved visualization of this region with TEE revealed that the noncoronary cusp was torn. Ini-

Fig. 2. Bland-Altman plot demonstrating the agreement between aortic annular measurements obtained by the first experienced reader (prospective study) by combined TTE and TEE approaches and the measurements obtained at the time of operation with a ring valve sizer. The 0 line (solid line) corresponds to the line of perfect agreement. The middle dashed line represents the mean difference. Upper and lower dashed lines correspond, respectively, to the upper and lower limits of agreement. SD, Standard deviation.

tially, improper alignment of the aortic root and sinuses resulted in an erroneously large measurement of the aortic annulus (see Fig. 6, A). After frequent scanning from the short to long axis, correct alignment of the aortic root and sinuses was obtained, resulting in an accurate annular measurement that was confirmed at the time of operation (see Fig. 6, B).

Another example (Fig. 7, A) illustrates a case of pure aortic insufficiency resulting from a dilated aortic root and malcoaption of thickened aortic cusps. In this case, the sinuses of Valsalva were symmetrically oriented, resulting in an accurate echocardiographic aortic annular measurement (confirmed during the operation) despite the presence of a dilated aortic root.

The third example (Fig. 7, B) illustrates a dilated bicuspid aortic valve that exhibited markedly reduced leaflet excursion coupled with gross asymmetry of the sinuses of Valsalva and mildly calcified aortic root.

Fig. 3. Bland-Altman plot demonstrating the agreement between aortic annular measurements obtained by the second experienced reader (retrospective study) by TTE or TEE and measurements obtained at the time of operation with a ring valve sizer. The 0 line (solid line) corresponds to the line of perfect agreement. The middle dashed line represents the mean difference. Upper and lower dashed lines correspond, respectively, to the upper and lower limits of agreement. SD, Standard deviation.

Discussion

The current study has demonstrated the feasibility and accuracy of prospective aortic diameter measurements through the use of multiplane TEE for preoperative selection and preparation of homograft aortic valves. Although previous studies have demonstrated that preoperative measurement of aortic annular diameter from two-dimensional TEE approximates prosthetic aortic valve annular diameter for most patients undergoing primary aor-

Fig. 4. Bland-Altman plot demonstrating the agreement between aortic annular measurements obtained by the intermediate reader by TTE or TEE and measurements obtained at the time of operation with a ring valve sizer. The 0 line (solid line) corresponds to the line of perfect agreement. The middle dashed line represents the mean difference. Upper and lower dashed lines correspond, respectively, to the upper and lower limits of agreement. SD, Standard deviation.

Fig. 5. Bland-Altman plot demonstrating the agreement between aortic annular measurements obtained by the inexperienced reader by TTE or TEE and measurements obtained at the time of operation with a ring valve sizer. The 0 line (solid line) corresponds to the line of perfect agreement. The middle dashed line represents the mean difference. Upper and lower dashed lines correspond, respectively, to the upper and lower limits of agreement. SD, Standard deviation.

tic valve replacement, a significant minority of estimates may be grossly inaccurate.^{4, 6-13} These potential inaccuracies render the prospective clinical use of transthoracic measurements unreliable for preoperative selection and preparation of aortic homografts.

Our previous study⁴ demonstrated that, although the bias of the transthoracic aortic annular measurements relative to prosthetic measurements was small (≥ 0.26 mm) and limits of agreement narrow, measurement errors were made in a few cases that resulted in excessively high confidence intervals for

individual patients. The results of that study were confirmed by Greaves and colleagues,¹¹ who reported differences greater than 2 mm between echocardiographic and prosthetic valve annular measurements for 54 (30%) of 178 patients. We have found that these discrepancies are caused by poor acoustic windows, heavily calcified aortic valves that result in acoustic shadowing, and dilated aortic roots caused by bicuspid valves, ruptured leaflets, or aneurysmal defects. All these defects may result in distorted anatomic landmarks and preclude adequate visual-

Fig. 6. Still frames (longitudinal views) obtained from a patient with a torn noncoronary aortic cusp diagnosed with the use of TEE. **A**, Improper alignment of the sinuses of Valsalva, which resulted in an erroneously large annular measurement of 27 mm. **B**, Still frame (longitudinal view) obtained from the same patient after realignment of the sinuses of Valsalva and aortic root. Proper positioning enabled accurate determination of the aortic annular size (23 mm), which was confirmed at the time of operation.

Fig. 7. Still frames (longitudinal views) obtained from two patients with bicuspid aortic valves and dilated aortic roots with the use of multiplane TEE. **A**, This patient had predominant aortic regurgitation. Notice the symmetry of the sinuses of Valsalva, with an annular diameter size of 30 mm. **B**, In this patient with aortic stenosis, there was marked asymmetry of the sinuses of Valsalva, with an annular diameter of 25 mm. Frequent scanning from the short to the long axis clearly identified the correct leaflet insertion sites into the aortic root. *RV*, Right ventricle; *LA*, left atrium; *AO ROOT*, aortic root.

ization of the insertion site of the aortic cusp's attachment to the aortic root.

This study demonstrated that measurements of the aortic annular diameter with combined TTE and TEE images are feasible and clinically useful for the preoperative selection and preparation of homograft aortic valves. We found that the highest accuracy for the prediction of annular diameter was obtained by the experienced reader when combining the echocardiographic information provided by both approaches (see Fig. 2). These findings were documented by the excellent agreement (positive bias of 0.2 mm; 95% confidence intervals: -1.2 to +1.6 mm) for all patients between preoperative echocardiographic measurements and those obtained with a ring valve sizer at the time of operation. The explanation for the additional accuracy conferred by the combined approach is the ability to circumvent the limitations to visualization of the leaflet insertion sites imposed by anterior acoustic shadowing originating from heavily calcified aortic valves. With the use of TTE or TEE, the acoustic shadowing is projected to the posterior or anterior aortic root wall, respectively. The results obtained with one technique can be confirmed by the second technique. Intertechnique concordance adds reliance to the preoperative measurements, whereas discordance should lead to additional measurements until consistency is achieved.

In the retrospective study, TEE measurements increased the accuracy of aortic annular measurements only for the experienced reader (see Fig. 3). TEE is better for imaging the aortic root because the technique obviates distortion of the ultrasonic signal by bony tissue and air and because it reduces the distance that the signal must travel. As a result, higher transducer frequencies can be used and image resolution is improved.

The accuracy of the measurements obtained by the intermediate and novice readers did not statistically improve with the use of TEE when compared with the transthoracic approach (see Figs. 4 and 5). This discrepancy may reflect the shorter time spent by these readers in TEE training than TTE training.

For either approach, it appears that the level of expertise in echocardiographic interpretation influences the accuracy of preoperative aortic annular measurements. For example, with the use of the TTE or the TEE modality, the intermediate and novice readers were inaccurate by more than 2 mm for 14 (56%) of 25 and 19 (76%) of 25 patients, respectively. In contrast, the experienced reader

obtained inaccurate measurements exceeding 2 mm for only two (8%) of 25 patients. A discrepancy of ≥ 2 mm between the preoperative echocardiographic measurement and the real annular diameter becomes clinically relevant, because it constitutes the limit of measurement error that still allows the insertion of an adequately sized homograft aortic valve.

It is important to optimize the echocardiographic images for measuring the aortic annular diameter. Acquisition of precise and dependable data requires a period of learning and validation in the institution in which this technique will be used, as demonstrated by the increased accuracy observed with the level of increased experience of the readers in this study. If the proposed method is followed closely, accurate and reproducible annular measurements can be obtained, as evidenced by the low interobserver and intraobserver variabilities.

This study is the first to prospectively evaluate and demonstrate the feasibility of obtaining accurate preoperative measurements of the aortic annulus for the selection and preparation of homograft aortic valves with the use of TTE combined with multiplane TEE. Although, the ischemic intraoperative time was not quantitated in this study, it is estimated that this time was shortened by 20 to 30 minutes in examining each of our patients. This interval is the average required for intraoperative measurement of the aortic annulus and subsequent thawing, trimming, and preparation of the homograft aortic valve.⁴

This study demonstrated the feasibility and accuracy of our combined echocardiographic approach for the preoperative measurement of the aortic annulus. The results stress the importance of the reader's experience. Routine clinical application of this technique should allow a reduction of the intraoperative ischemic time and circumvent inventory limitations.

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