# Transesophageal Echocardiographic Evaluation of Native Aortic Valve Area: Utility of the Double-Envelope Technique

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**_Objective:_ To assess the accuracy of aortic valve area (AVA) calculations using the continuity equation with data obtained from the double envelope (DE) (simultaneously obtained left ventricular outflow tract [$V_1$]) and aortic valve [$V_2$] velocities) during intraoperative transesophageal echocardiography (TEE).**

**_Design:_ Prospective study; measurements were performed on-line.**

**_Setting:_ University hospital.**

**_Participants:_ Cardiac and noncardiac surgical patients (n = 75) with recent aortic valve assessment (<3 months) undergoing general anesthesia or endotracheal intubation.**

**_Interventions:_ Intraoperative AVA was measured by the continuity equation using the DE technique (DE/TEE) and by planimetry (PL/TEE). Left ventricular outflow tract diameter was obtained from midesophageal views, whereas subvalvular ($V_1$) and valvular ($V_2$) velocities were obtained simultaneously using continuous-wave Doppler from transgastric views. $V_1$ was also obtained using pulsed-wave Doppler. Measurements were compared with AVA obtained preoperatively by the Gorlin equation during cardiac catheterization (G/CATH) or by transthoracic echocardiography using the traditional continuity equation (C/TTE) (nonsimultaneously obtained $V_1$ and $V_2$).**

**_Measurements and Main Results:_ A DE was obtained in 73 of 75 patients (97%). Four patients had atrial fibrillation at the time of the examination, whereas the rest were in sinus rhythm. PL/TEE was performed in 54 of 71 patients with sinus rhythm (76%). Agreement was good between DE/TEE and G/CATH (mean bias, 0.02 cm$^2$ [SD, 0.24 cm$^2$]), and C/TTE (mean bias, −0.05 cm$^2$ [SD, 0.16 cm$^2$]). Agreement was not as good between PL/TEE and G/CATH (mean bias, −0.07 cm$^2$ [SD, 0.28 cm$^2$]) and C/TTE (mean bias, −0.13 cm$^2$ [SD, 0.30 cm$^2$]). $V_1$ obtained by pulsed-wave Doppler and with DE closely agreed (mean bias, 0.01 m/sec [SD, 0.05 m/sec]).**

**_Conclusion:_ TEE evaluation of native AVA using the DE technique is feasible and in good agreement with that obtained by C/TTE and G/CATH. Compared with DE/TEE, PL/TEE did not agree as well. Use of DE/TEE should simplify the continuity equation and may minimize errors resulting from beat-to-beat variability in stroke volume.**



***KEY WORDS: echocardiography, transesophageal, aortic valve, stenosis, double envelope, planimetry***

QUANTITATIVE DOPPLER assessment of the severity of native aortic valve stenosis includes measurement of transvalvular peak velocities, pressure gradient, and calculation of aortic valve area (AVA) using the continuity equation (Equation 1).[1-10] Traditionally, the continuity equation involves nonsimultaneous measurements of the peak flow velocities of the left ventricular outflow tract (LVOT; $V_1$) and across the aortic valve (AoV; $V_2$) orifice using pulsed-wave and continuous-wave Doppler.[2-5,8,9,11-14] Because LVOT and AoV velocities are obtained at different times, errors can result from physiologic beat-to-beat variability in blood flow, the result of changing loading conditions, or myocardial function.

Equation 1: Continuity Equation

$$\text{Area}_{\text{AoV}} = \text{Area}_{\text{LVOT}}(\text{Velocity}_{\text{LVOT}})/\text{Velocity}_{\text{AoV}})$$

$$\text{Area}_{\text{AoV}} = \pi(\text{D}_{\text{LVOT}}/2)^2(\text{Velocity}_{\text{LVOT}}/\text{Velocity}_{\text{AoV}})$$

$$\text{Area} = \pi r^2 = \pi(\text{D}/2)^2$$

$$r = \text{radius; D} = \text{diameter}$$

The authors have noticed during transesophageal echocardiography (TEE) examination that a lower velocity flow profile can be seen within the time velocity integral (TVI) generated from continuous-wave Doppler examination of the aortic valve, making a *double envelope* (DE) (Fig 1). It was postulated that this inner envelope represents subvalvular blood flow ($V_1$) (ie, is equivalent to pulsed-wave measurement of LVOT velocity) and can be used to calculate AVA; this has been shown during transthoracic echocardiography (TTE) examination in a few patients.[15] The purpose of this study was to assess the accuracy of native AVA calculations using the DE during the TEE examination. It was hypothesized that assessment of the aortic valve can be simplified, and the AVA can be accurately calculated during TEE using the DE technique.

## METHODS

This study was approved by the hospital research internal review board. A total of 75 consecutive patients with a recent evaluation (<3 months) for aortic valve disease scheduled for cardiac and noncardiac surgery requiring general anesthesia with endotracheal intubation were prospectively studied (Table 1). In all patients, TEE was used as part of the clinical care of the patient. Adequate imaging was achieved in 73 of 75 patients. Echocardiographers (A.D.M., J.M., J.M.H.) were blinded to previous data regarding the patient's cardiovascular function and aortic valve assessment. All echocardiographers were anesthesiologists with specialty training in echocardiography.

Preoperative calculation of AVA was accomplished using the traditional continuity equation during TTE (C/TTE) or the Gorlin equation during cardiac catheterization (G/CATH) (Equation 2). The former employs nonsimultaneous measurement of the LVOT and AoV peak velocities, whereas the latter employs measurement of blood flow as measured by Fick cardiac output.

Equation 2: Gorlin Equation

$$\text{Area}_{\text{AoV}} = \text{Q}/(44.3 \times \text{MPG}^{1/2})$$

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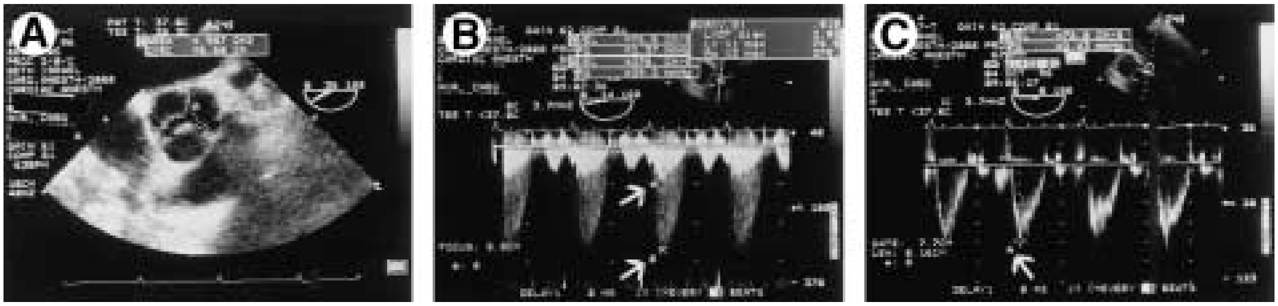



**Fig 1. Measurement of aortic valve area (AVA) using planimetry and the double-envelope technique in a patient with sinus rhythm. Aortic valve measurement using planimetry (AVA, 0.99 cm²) (A). The double-envelope technique obtained using continuous-wave Doppler (AVA, 0.91 cm²) (B). Pulsed-wave Doppler of the left ventricular outflow tract (C). Note the similarity between pulsed-wave and continuous-wave Doppler in measuring the left ventricular outflow tract flow velocity (76.5 cm/sec *v* 78.0 cm/sec).**

Q = blood flow across the aortic valve

44.3 = constant

MPG = Mean pressure gradient across the aortic valve

Additional echocardiographic data included assessment of left ventricular ejection fraction, mitral regurgitation, and aortic insufficiency. Left ventricular ejection fraction was assessed from midesophageal 4-chamber and 2-chamber and long-axis windows and from transgastric mid-short-axis and long-axis views using visual inspection.[16-18] Mitral regurgitation was assessed from midesophageal views including the 4-chamber and 2-chamber and long-axis windows. Assignment of severity (mild, moderate, and severe) was based on the color Doppler jet area, extent, and direction (eccentric *v* central) and pulmonary venous Doppler trace.[19] Aortic insufficiency was assessed from the midesophageal aortic valve short-axis and long-axis windows. Assignment of severity was based on the ratio of the aortic insufficiency jet height to the diameter of the LVOT.[19]

**Table 1. Demographic and Perioperative Data**

| | |
|---|---|
| No. patients | 75 |
| Age (y) | 69 (±14 SD) |
| Surgical procedure (no.) | |
| AVR | 26 |
| AVR/CABG | 30 |
| AVR/MVR ± CABG | 7 |
| Aortic root surgery | 2 |
| Noncardiac | 8 |
| LVEF (%) | 48 (±12 SD) |
| Valve morphology (no.) | |
| Calcific | 71 |
| Redo AVR | 4 |
| Aortic insufficiency (no.) | |
| Trace to mild | 32 |
| Moderate | 33 |
| Severe | 8 |
| Mitral regurgitation (no.) | |
| Mild or less | 33 |
| Moderate | 31 |
| Moderate/severe to severe | 9 |
| Technique success (no.) | |
| DE/TEE | 73/75 (97%) |
| PL/TEE | 54/71 (76%) |

Abbreviations: AVR, aortic valve replacement; CABG, coronary artery bypass graft; MVR, mitral valve replacement; LVEF, left ventricular ejection fraction; DE/TEE, double envelope/transesophageal echocardiography; PL/TEE, planimetry/transesophageal echocardiography.

After induction of general anesthesia and endotracheal intubation, a multiplane TEE probe (5.0/3.5 MHz multiplane probe, Hewlett Packard, Andover, MA) was placed, and a baseline echocardiographic examination was performed (Sonos 2500 and Sonos 2000, Hewlett Packard, Andover, MA). Three calculations of AVA were performed in each patient from 3 separate cardiac cycles using the DE technique and planimetry. These calculations were averaged to obtain a mean AVA. To assess variability of individual Doppler measurements, 5 calculations of AVA were performed in a subset of 20 consecutive patients (patients 40 through 60; 1 patient had inadequate windows for evaluation). All measurements and calculations were performed on-line.

LVOT diameter was measured during TEE examination from the midesophageal long-axis window as previously described.[2-4] The esophageal view was considered suitable for measurement of LVOT diameter when the LVOT, the aortic valve, and the proximal ascending aorta were visualized. This visualization occurred with the transducer rotated between 110° and 145°. The diameter was measured using the inner edges of the LVOT in the immediate subvalvular location.

Doppler assessment of LVOT and AoV blood flow was performed from transgastric long-axis and deep transgastric windows.[2-4,15,20-22] The ultrasound transducer and TEE probe were manipulated and rotated to give a clear velocity envelope. Peak velocities were used to calculate AVA, as previously described.[2-4] Doppler gains were adjusted to enhance the distinction of the 2 velocity profiles: the inner velocity representing $V_1$ and the higher velocity representing $V_2$. The maximal transvalvular velocity ($V_2$) was sought. As described in the literature, blood flow across the LVOT and AoV was assessed from a variety of transducer positions (0° to 155°).[2-4,15,20-22] $V_1$ and $V_2$ were obtained from the same continuous-wave Doppler trace (DE) (Fig 1). For comparison, $V_1$ was assessed using pulsed-wave Doppler. The pulsed-wave sample volume was initially placed at the level of the aortic valve and withdrawn into the subvalvular space until aliasing ceased and a clear velocity envelope was obtained.[23] To calculate AVA, the simultaneously recorded $V_1$ and $V_2$ were applied to the continuity equation (DE/TEE).

AVA measurement was attempted using planimetry during 2-dimensional echocardiography examination (PL/TEE) from the midesophageal aortic valve short-axis window.[11,24] After the TEE probe was positioned in the esophagus at the level of the aortic valve, the transducer was rotated 40° to 60° to obtain a short-axis cross-sectional view of the aortic valve. When all 3 leaflet commissures were visible, the inner borders of the valve leaflets were traced to measure the AVA (Fig

1).[11-13,24-28] Measurements were made in early systole during brief periods of apnea.

All data were averaged and presented as the mean ± SD. Intraoperative TEE measurements of AVA using DE/TEE and PL/TEE were compared with preoperative measurements (C/TTE and G/CATH) using regression and bias analyses. Comparisons were made between the $V_1$ obtained from continuous-wave (DE) and pulsed-wave Doppler tracings using regression and bias analyses. For regression statistics, a $p$ value $< 0.05$ was taken to be significant. Results from regression analyses include $r$ and $p$ values. Results from bias analyses include the mean bias, SD, and the 95% confidence interval.

Beat-to-beat variability was assessed in a subset of patients from 5 measurements obtained from 5 separate cardiac cycles at various times during the TEE examination. Mean valve area, SD, and the coefficient of variation (SD/mean) were calculated for each patient. From these results, the mean valve area, SD, and coefficient of variation were calculated for this subset of patients. In 10 patients, 2 echocardiographers performed separate blinded analyses. Interobserver variability was assessed in the subset of patients using bias analyses.

## RESULTS

DE/TEE was successfully performed in 73 of 75 patients (97%). Of the patients, 69 had a sinus rhythm, and 4 patients had atrial fibrillation. Forty-six and 43 patients had a preoperative AVA measured by Gorlin equation (G/CATH) and the continuity equation (C/TTE). PL/TEE was not performed in the 4 patients with atrial fibrillation. Planimetry was successfully performed in 54 of 71 (76%) patients. Descriptive data are presented in Table 1. Results of the regression and bias analyses are presented in Table 2.

Good agreement was seen between AVA measured by DE/TEE and G/CATH (n = 42; $r^2 = 0.70$; mean bias, 0.02 cm²; SD, 0.24 cm²; 95% confidence interval, −0.05 to 0.10 cm²) and between DE/TEE and C/TTE (n = 39; $r^2 = 0.73$; mean bias, −0.05 cm²; SD, 0.16 cm²; 95% confidence interval, −0.11 to 0.00 cm²) (Fig 2). Compared with DE/TEE, agreement between PL/TEE and G/CATH (n = 34; $r^2 = 0.32$; mean bias, −0.07 cm²; SD, 0.28 cm²; 95% confidence interval, −0.17 to 0.03 cm²) and C/TTE (n = 31; $r^2 = 0.12$; mean bias, −0.13 cm²; SD, 0.30 cm²; 95% confidence interval, −0.24 to −0.02 cm²) was not as good (Fig 3). For the 4 patients with atrial fibrillation, good agreement was seen between DE/TEE and G/CATH (mean bias, 0.12 cm²; SD, 0.11 cm²) and with C/TTE (mean bias, 0.03 cm²; SD, 0.25 cm²). In these 4 patients, the mean bias between C/TTE and G/CATH was 0.09 cm² (SD, 0.18 cm²). Agreement between C/TTE and G/CATH was good (n = 38; $r^2 = 0.74$; mean bias, 0.08 cm²; SD, 0.21 cm²; 95% confidence interval, 0.01 to 0.16 cm²) (Fig 4).

Of the 73 patients studied with Doppler echocardiography, 58 had AVA < 1.0 cm². The range of peak valvular gradients measured was 11.4 to 121.0 mmHg. Of the 58 patients with AVA < 1.0 cm², 2 had peak gradients across the aortic valve > 50 mmHg, and 6 had peak gradients of >30 mmHg. Sixteen patients had peak velocities <3 m/sec². Ten of these 16 patients had $V_2/V_1$ ratio ≥ 3.2 ($V_1/V_2 \leq 0.31$), and all 10 had a calculated valve area of ≤1.0 cm².

Forty-five patients had a $V_2/V_1$ ratio > 4:1, 42 of whom had AVA < 1.0 cm². Three of these patients had AVAs of 1.48 cm², 1.09 cm², and 1.01 cm². These patients had LVOT diameters of 2.88 cm, 2.59 cm, and 2.60 cm. There was good correlation between the velocity ratio ($V_1/V_2$ or $V_2/V_1$) and AVA ($r^2 = 0.69$; $p = 0.0001$), whereas $V_2$ or peak transvalvular gradient did not correlate as well with AVA ($r^2 = 0.18$). Of all patients with an AVA (DE/TEE) < 1.0 cm², only 1 patient had a $V_2/V_1$ ratio < 3.5:1. This $V_2/V_1$ ratio equaled 2.96:1 and the calculated valve area of 0.96 cm².

$V_1$ obtained using pulsed-wave Doppler was nearly identical to the $V_1$ obtained from the DE technique using continuous-wave Doppler (n = 69; pulsed-wave, 0.87 m/sec [SD, 0.19 m/sec] *v* continuous wave, 0.86 m/sec [SD, 0.19 m/sec]). The mean bias was 0.01 m/sec (SD, 0.05 m/sec; 95% confidence interval, 0.00 to 0.02 m/sec) (Fig 5).

Variability was assessed in 20 consecutive patients. Each patient had 5 separate measurements performed (5 nonconsecutive cardiac cycles). The mean AVA for this subgroup was 0.86 cm² (range, 0.55 to 2.34 cm²). The mean SD was 0.05 cm², and the mean coefficient of variation was 5.23%. Atrial fibrillation was present in 4 patients (Fig 2). The mean AVA for these 4 patients was 1.02 cm² (range, 0.68 to 1.60 cm²). The mean SD and coefficient of variation were 0.05 cm² and 5.84%.

Interobserver variability for AVA measurement using DE/TEE was assessed in 10 patients. Agreement between separate echocardiographers was excellent. The mean bias for AVA measurement between 2 echocardiographers using DE/TEE was 0.02 cm² (SD, 0.05 cm²).

**Table 2. Comparisons of AVA Measured by the Gorlin Equation (G/CATH), the Continuity Equation During Preoperative TTE (C/TTE), the Continuity Equation Using the Double-Envelope Technique During Transesophageal Echocardiography (DE/TEE), and Planimetry During TEE (PL/TEE)**

| Method | AVA (cm²) | Range (cm²) | Bias (cm²) |
|---|---|---|---|
| DE/TEE | | | |
| CATH | 0.85 | 0.40-2.40 | 0.03(0.24) |
| DE/TEE | 0.82 | 0.33-1.95 | |
| TTE | 0.77 | 0.40-1.90 | 0.05(0.17) |
| DE/TEE | 0.81 | 0.33-1.95 | |
| PL/TEE | | | |
| CATH | 0.78 | 0.40-2.00 | 0.09(0.30) |
| PL/TEE | 0.87 | 0.35-1.60 | |
| TTE | 0.69 | 0.40-1.20 | 0.15(0.32) |
| PL/TEE | 0.85 | 0.35-1.60 | |
| G/CATH *v* C/TTE | | | |
| CATH | 0.82 | 0.40-2.40 | 0.08(0.20) |
| TTE | 0.74 | 0.40-1.90 | |

NOTE. Data presented as mean AVA, mean bias (SD).

## DISCUSSION

This study shows that accurate quantitative Doppler assessment of the native aortic valve can be performed using DE/TEE. Low beat-to-beat variability was seen in patients with sinus rhythm and in a few patients with atrial fibrillation. Measurement of AVA by PL/TEE did not agree as well with preoperative AVA assessment, and it was not as obtainable as Doppler assessment.

Use of the DE has been reported during TTE.[15] Agreement was seen in patients with *flat* (as opposed to *doming* seen with

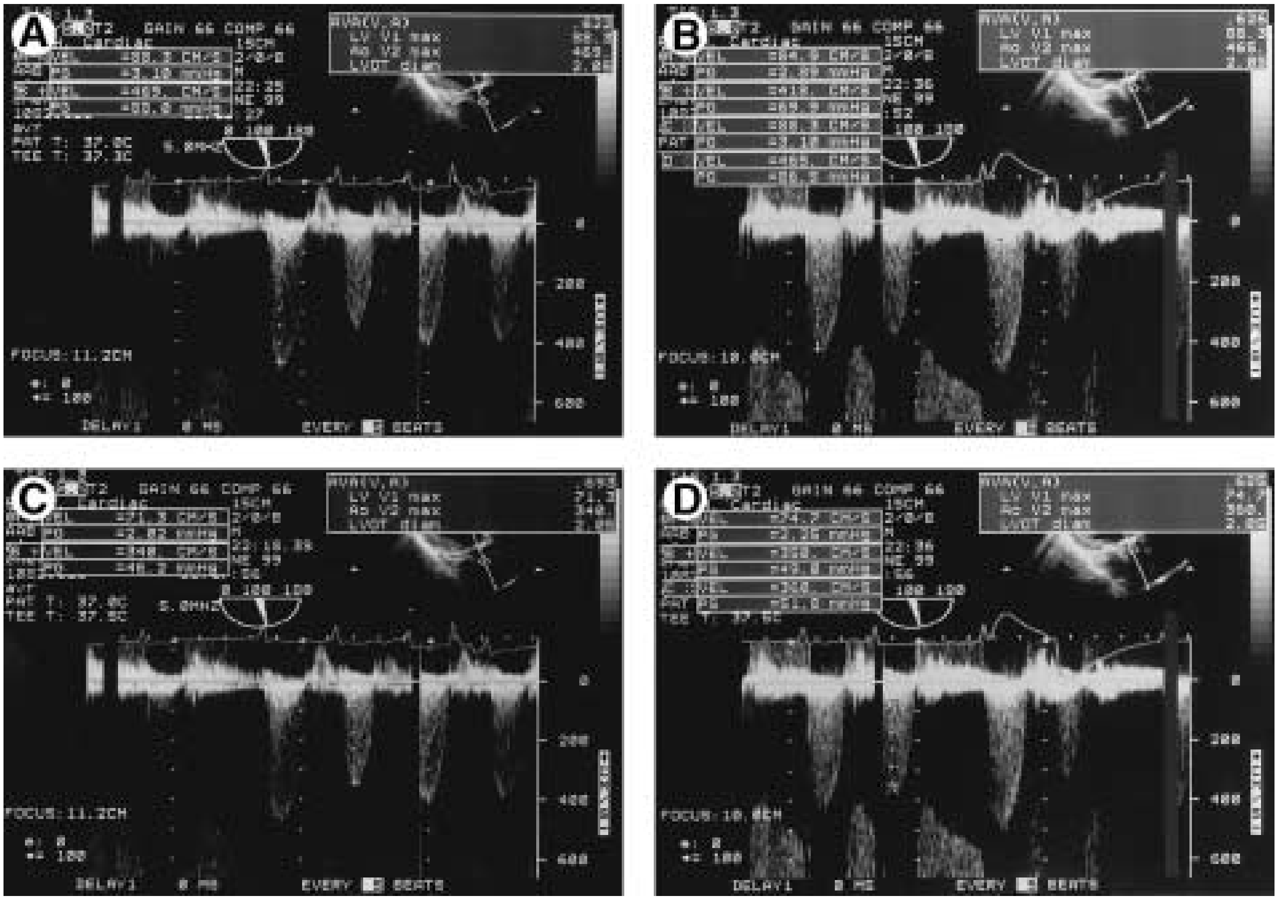



**Fig 2. Aortic valve area measurement using the double-envelope technique in a patient with atrial fibrillation. Note the variability in flow velocities as a result of beat-to-beat variability secondary to atrial fibrillation. Aortic valve area calculations ranged from 0.62 to 0.69 cm$^2$.**

bicuspid valves) aortic valvular stenosis. In this setting, the inner velocity of the DE ($V_1$) equaled the velocity at the valve annulus ($V_{ann}$) obtained using pulsed-wave Doppler. In valves with doming stenosis, the inner velocity of the DE ($V_1$) did not equal the velocity measured at the annulus. In these patients, $V_1$ was greater than the annular velocity ($V_{ann} = 0.7\ V_1$). The DE technique allows simultaneous measurement of LVOT and AoV velocities from a single continuous-wave velocity profile. It is accepted that the peak of the continuous-wave velocity trace is generated by blood flow across the most narrow point, which in the absence of subvalvular obstruction is the stenotic aortic valve orifice. The present data and that from a prior study show excellent agreement between the lower velocity profile of the DE with blood flow velocity obtained from the LVOT using pulsed-wave Doppler, suggesting that the inner envelope is generated from the immediate subvalvular location.[15]

Potential errors are introduced when calculating AVA using nonsimultaneous measurements of LVOT and AoV (C/TTE). Typically, 3 to 5 measurements of the LVOT and transvalvular peak velocities (total 6 to 10 measurements from 6 to 10 different cardiac cycles) are obtained and averaged.[1-4,9] The sampling is increased in patients with irregular rhythms.[1-4,9] Because velocities are obtained from different cardiac cycles, beat-to-beat variability in blood flow occurs, and coupling of LVOT and valve annulus velocities from differing stroke volumes is likely and will increase error.[24,29-35] Physiologic stroke volume variability produces error when nonsimultaneous blood flow velocities are used for calculation of AVA by 10% to 20%.[1] Because AVA is directly related to the instantaneous ratio of $V_1$ to $V_2$, simultaneous measurement of these 2 velocities should improve accuracy. This study showed little beat-to-beat variability of the velocity ratio ($V_1/V_2$) and calculated AVA from one cardiac cycle to another. Conceivably, accurate AVA can be calculated from a single continuous-wave velocity profile using the DE technique.

According to the continuity equation, calculation of AVA is directly related to the velocity ratio of the LVOT ($V_1$) to the AoV ($V_2$).[9,36] Perakis et al[36] showed that severe aortic stenosis was associated with a $V_1/V_2$ ratio of $\leq 0.25$ ($V_2/V_1 \geq 4{:}1$). The average LVOT diameter in adult patients has been reported to be 1.9 to 2.1 cm$^2$.[1,8] If it is assumed that the mean LVOT diameter is 2.0 cm$^2$ and the upper limit is approximately 2.25 cm$^2$, a $V_1/V_2$ ratio equal to 0.25 would be associated with an AVA of 0.75 cm$^2$ and 1.0 cm$^2$. A $V_2/V_1$ ratio of 3.2:1 ($V_1/V_2 = 0.31$) would result in a valve area $< 1.0$ cm$^2$ when the LVOT diameter is 2.0 cm.

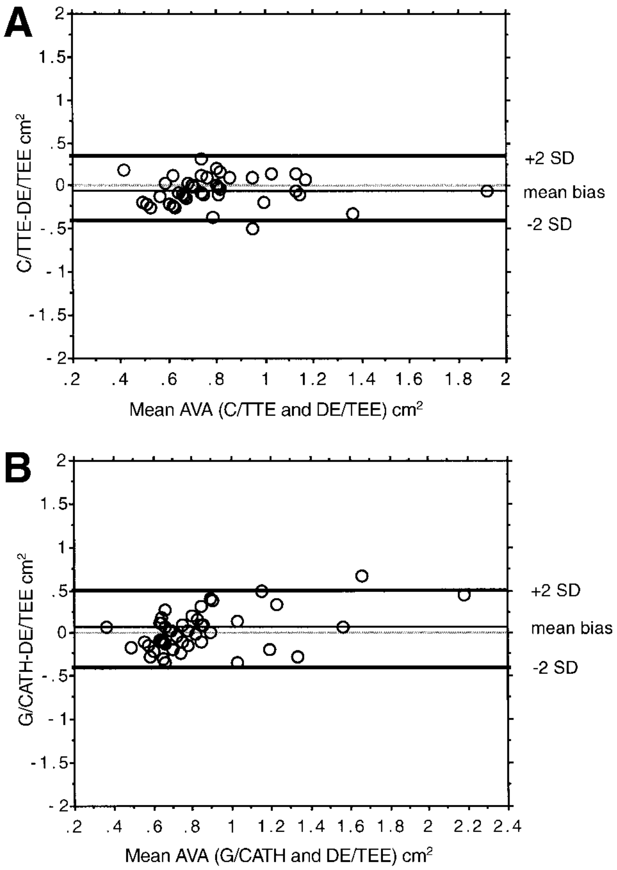



**Fig 3. Bias analyses comparing aortic valve areas (AVAs) obtained using the double-envelope technique during transesophageal echocardiography (DE/TEE) with (A) the conventional continuity equation during preoperative transthoracic echocardiography (C/TTE) (mean bias, $-0.05$ cm$^2$; SD, 0.16 cm$^2$) and with (B) the Gorlin equation during preoperative cardiac catheterization (G/CATH) (mean bias, 0.02 cm$^2$; SD, 0.24 cm$^2$).**

The clinical significance of varying degrees of aortic valve stenosis is not always well defined.[5-10] Symptoms, peak velocities and mean pressure gradients, and the AVA are used to describe the severity of aortic stenosis.[5-10] It is important to define severity so as to determine the cause of a patient's cardiopulmonary symptoms and to time surgical therapy appropriately.[10] A valve area $< 0.8$ cm$^2$ is considered severe and is associated with symptoms (congestive heart failure, angina, syncope) and increased morbidity (valve replacement) and mortality.[1,6,7,9,10] AVAs $> 0.8$ cm$^2$ may have varying clinical significance in individual patients, however.[5-7] Several investigators have proposed different measures, or indices, of severity to determine the clinical significance of different degrees of aortic valve stenosis. Indexing valve area according to the patient's body surface area or patient height has been proposed.[1,38] An AVA index $< 0.7$ has been equated to moderate valvular stenosis.[1] This value has been shown to be predictive of morbidity after prosthetic aortic valve replacement.[37] Royse et al[38] showed that LVOT area was more predictive of AVA compared with height and body surface area, however. Otto et al[5,8,9] suggested a simpler severity index based on peak valvular velocity. These investigators proposed that a peak AoV velocity ($V_2$) $> 4$ m/sec is associated with clinically significant aortic stenosis and predictive of aortic valve replacement, whereas a velocity $< 3$ m/sec suggests that valve replacement is not immediately necessary.[9] A peak velocity between 3 and 4 m/sec would require further assessment.[9] Because blood flow velocity depends on hemodynamic performance as well as valve orifice, significant aortic stenosis may be seen with velocities $< 3$ m/sec, especially in the presence of left ventricular systolic dysfunction, mitral regurgitation, or reduction in ventricular preload.[8] Otto et al[8] reported a high prevalence of severe aortic stenosis in patients with low peak transvalvular velocities and ventricular systolic dysfunction. Sixteen patients in this study had peak velocities $< 3$ m/sec$^2$. Ten of these 16 patients had AVAs $< 1.0$ cm$^2$.

In the absence of subvalvular pathology or obstruction, the velocity ratio ($V_2/V_1$ or $V_1/V_2$) may be a useful index of valve function. Calculation of AVA is directly related to the velocity ratio. In the present study, a velocity ratio $\geq$ 4:1 ($V_1/V_2 \geq 0.25$) was associated with AVA $< 1.0$ cm$^2$ in all patients except 3

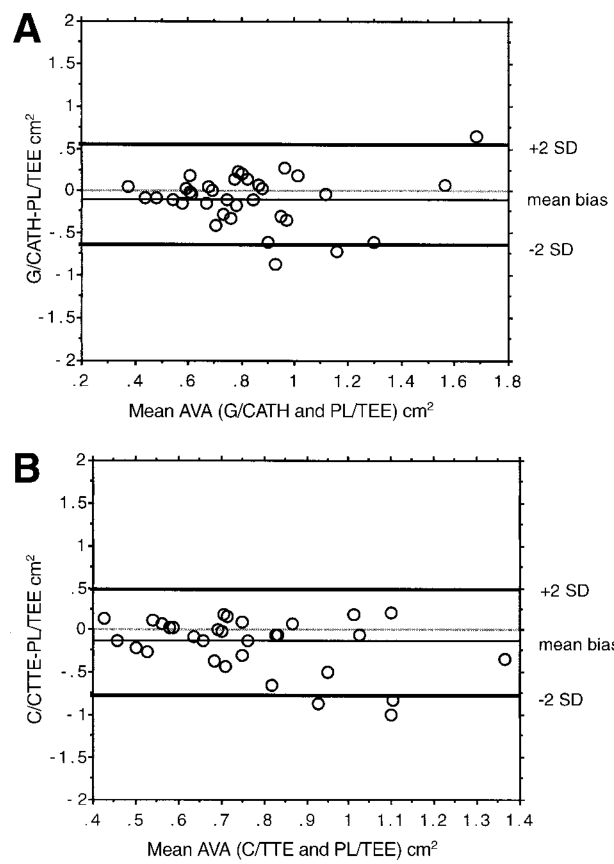
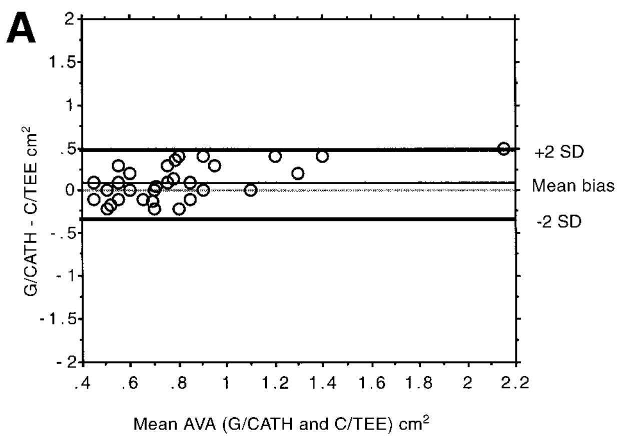



**Fig 4. Bias analyses comparing aortic valve areas (AVAs) obtained using planimetry during transesophageal echocardiography (PL/TEE) with (A) the conventional continuity equation during preoperative transthoracic echocardiography (C/TTE) (mean bias, $-0.13$ cm$^2$; SD, 0.30 cm$^2$) and with (B) the Gorlin equation during preoperative cardiac catheterization (G/CATH) (mean bias, $-0.07$ cm$^2$; SD, 0.28 cm$^2$).**



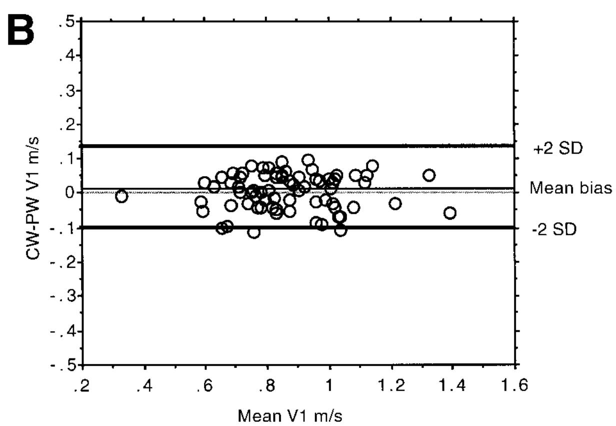




**Fig 5. (A) The bias analysis comparing preoperative aortic valve area (AVA) calculations obtained using the conventional continuity equation during preoperative transthoracic echocardiography (C/TTE) and using the Gorlin equation during preoperative cardiac catheterization (G/CATH) (mean bias, 0.08 cm$^2$; SD, 0.20 cm$^2$). (B) The bias analysis comparing the left ventricular outflow tract (LVOT) velocities ($V_1$) obtained using pulse-wave Doppler and from the double-envelope (DE) during continuous-wave Doppler (mean bias 0.01 m/sec; SD 0.05 m/sec).**

(1.48 cm$^2$, 1.09 cm$^2$, and 1.01 cm$^2$). These 3 patients had LVOT diameters ($\geq$2.59 cm) that were $>$2 SDs from the study mean (2.06 cm; SD, 0.23 cm). The velocity ratio correlated well with AVA in this study and in another investigation.[8] In this latter study, symptomatic patients had velocity ratios $\leq$ 0.35.[8] Concordantly, this ratio has been found to be associated with symptomatic patients with a bioprosthetic valve stenosis in the aortic position.[39] Otto et al[8] suggested that the ". . . velocity ratio is already 'indexed' for body size . . . ." If a velocity ratio of 1.0 would suggest no significant stenosis, a velocity ratio of 0.3 ($V_1/V_2$) or 3.1 ($V_2/V_1$) suggests that the AVA has decreased to one third of its original size.

Previous investigations evaluated the accuracy of planimetry in the assessment of AVA.[11-13,25-28,40,41] The introduction of multiplane TEE has enhanced the performance of planimetry,[12,40] such that it is feasible in $\geq$78% of patients.[11-13,25-28,40-42] Inability to perform aortic valve planimetry occurs with imaging artifacts, poor acoustic windows, and heavy calcification of the aortic valve resulting in excessive acoustic shadowing.[26-28] In the present study, planimetry was less feasible (76%) and less accurate than DE/TEE when compared with preoperative data. Bernard et al[42] reported poor correlation between planimetry and assessments made during cardiac catheterization (G/CATH) and during transthoracic echocardiography (C/TTE). These authors explained that the "aortic valve is neither planar nor a fixed orifice."[42] Because it is not planar, 1 cusp may be out of plane from the other two.[42]

Previous investigations have showed the accuracy of planimetry, and this method has been used to assess alternate technologies.[11-13,25-28,40,41] The present results do not support this. It is possible that a learning curve exists for the performance of planimetry similar to one shown for Doppler assessment.[2]

A limitation to this study is the absence of a true gold standard for measurement of AVA to compare with the data.[1,32-34,43] There are potential errors of the DE technique. Although the peak velocity across the aortic valve was sought, it is possible that the ultrasound beam was not on line with the peak LVOT blood flow. Although excellent agreement with $V_1$ measured using pulsed-wave Doppler was shown, it is possible that a higher blood flow velocity in the LVOT may be found from another acoustic window. If this were the case, the calculated $V_1/V_2$ would underestimate the true velocity ratio, resulting in an overestimation of aortic valve stenosis severity.

In conclusion, this study showed the feasibility and accuracy of quantitative Doppler assessment of native aortic valve function using DE/TEE. The DE technique simplifies echocardiographic assessment and may improve accuracy, by minimizing error secondary to beat-to-beat variability in blood flow when using nonsimultaneous measures of LVOT and AoV velocities. Calculation of a velocity ratio ($V_2/V_1$ or $V_1/V_2$) may obviate the need to calculate AVA and may provide a more clinically relevant index of disease severity. Advantages regarding the velocity ratio require further evaluation, however.

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