Value and Limitations of Transesophageal Echocardiography in Determination of Left Ventricular Volumes and Ejection Fraction

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Several formulas exist for estimating left ventricular volumes and ejection fraction using conventional two-dimensional echocardiography from transthoracic views. Transesophageal imaging provides superior resolution of endocardial borders but employs slightly different scan planes. The estimation of left ventricular volumes by transesophageal echocardiography has not been validated in human patients. Therefore, the purpose of this study was to compare left ventricular volumes and ejection fraction derived from transesophageal short-axis and four-chamber images with similar variables obtained from ventriculography.

End-diastolic and end-systolic volumes and ejection fraction were calculated using modified Simpson's rule, area-length and diameter-length models in 36 patients undergoing left ventriculography. Measurements of left ventricular length were obtained from the transesophageal four-chamber view and areas and diameters were taken from short-axis scans at the mitral valve, papillary muscle and apex levels.

Data from transesophageal echocardiographic calculations were compared with end-diastolic volume (mean 172 ± 90 ml), end-systolic volume (mean 91 ± 74 ml) and ejection fraction (mean 52 ± 15%) from cineventriculography using linear regression analysis. The area-length method (r = 0.88) resulted in a slightly better correlation with left ventricular end-diastolic volume than did Simpson's rule (r = 0.85) or area-length (r = 0.84) formulas. For end-systolic volume, the three models yielded similar correlations: Simpson's rule (r = 0.94), area-length (r = 0.93) and diameter-length (r = 0.95). Each of the methods resulted in significant underestimation of diastolic and systolic volumes compared with values assessed with angiography (p < 0.003).

Ejection fraction was best predicted by using the Simpson's rule formula (r = 0.85) in comparison with area-length (r = 0.80) or diameter-length (r = 0.73) formulas. Measurements of left ventricular length by transesophageal echocardiography were smaller for systole (mean 5.7 ± 1.6 cm) and diastole (mean 7.7 ± 1.2 cm) than values by ventriculography (mean 9.2 ± 1.4 and 8.1 ± 1.6 cm, respectively; p < 0.0001), suggesting that underestimation of the ventricular length is a major factor contributing to the smaller volumes obtained by transesophageal echocardiography.

In conclusion, currently existing formulas can be applied to transesophageal images for predicting left ventricular volumes and ejection fraction. However, volumes obtained by these models are significantly smaller than those obtained with angiography, possibly because of foreshortening in the transesophageal four-chamber view.

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A number of geometric algorithms have been applied to calculate left ventricular volume from standard transthoracic two-dimensional echocardiographic images (1-6). These methods commonly employ apical and short-axis planes and assume that the left ventricle can be represented by a three-dimensional figure such as a prolate ellipsoid (2-4). Imaging from the transesophageal window provides enhanced resolution of endocardial borders as a result of shallow imaging depths and reduced acoustic impedance but scan planes may differ slightly from those of transthoracic studies (7). In addition, the number of tomographic slices available with this technique is often limited by the constraint of the wall of the esophagus and stomach on transducer position and the spatial relation of these organs to the heart.

At present, the estimation of left ventricular volumes by using currently available standard transesophageal imaging planes has not been validated in humans. Therefore, in this study we compared two-dimensional echographic estimates of left ventricular end-diastolic and end-systolic volumes and ejection fraction obtained from transesophageal scans with corresponding measurements derived from ventricular angiography. Specifically, we sought to determine which of three commonly applied algorithms provides the best estimate of angiographic volumes by transesophageal echocardiography: Simpson's rule, area-length or diameter-length formulas (2).
Methods

Study patients. Videotapes were retrospectively reviewed from 42 consecutive patients who had undergone a transesophageal two-dimensional echocardiographic study and left ventriculography. All patients who were in sinus rhythm and had technically adequate transesophageal echocardiographic and angiographic studies for analysis were included. Three patients with atrial fibrillation and three with ventricular ectopic activity during ventriculography were excluded. No patients were excluded because of inadequate transesophageal images. Thus, the final study group consisted of 30 men and 6 women, with a mean age of 57 ± 13 years (range 29 to 75). The mean interval between catheterization and transesophageal echocardiographic study was 17 ± 27 days and 15 studies were performed within 48 h of each other. No change in clinical status occurred in the interval between examinations. Twenty-seven transesophageal echocardiographic examinations were performed intraoperatively in anesthetized patients and nine were done in the noninvasive laboratory in awake patients. The underlying diagnoses for the patients undergoing transesophageal studies were mitral valve disease (n = 10), aortic valve disease (n = 9), ischemic heart disease (n = 7), left atrial myxoma (n = 3) and constrictive pericarditis (n = 1). Of the seven patients with ischemic disease, four had regional wall motion abnormalities by ventriculography, two of whom had a history of prior myocardial infarction.

Transesophageal echocardiography. Intraoperative transesophageal studies were performed after induction of general anesthesia and tracheal intubation but before sternotomy, with the patient supine on the operating room table and in stable hemodynamic condition. Scans were obtained in the noninvasive laboratory after application of xylocaine spray to the posterior pharynx and administration of intravenous glycopyrrolate and midazolam (8).

Transesophageal imaging was accomplished with three commercially available single-plane probes with 5-MHz transducers (HP770204 Hewlett-Packard; Aloka 860, Corometrics Medical Systems, Inc.; Acuson 128 C/F). All patients underwent complete echocardiographic and Doppler examinations employing previously described (8) transesophageal scan planes. The four-chamber scans were obtained by inserting the probe to a depth of approximately 30 cm from the incisors and retroflexion of the tip. Care was taken to ensure that the internal crux, both mitral and tricuspid valves, the interventricular and interatrial septa as well as the cardiac apex were properly aligned and included in the image sector. Acoustic power and gray levels were then appropriately adjusted to allow for optimal real time imaging of the complete circumference of left ventricular endocardial border from base to apex.

The short-axis scans were obtained by further advancement of the transducer toward or past the gastroesophageal junction to a 35 to 40 cm depth. By adjusting the depth of the probe and with various degrees of anteflexion of the tip, cross-sectional images of the left ventricle were obtained at the mitral leaflet level, high papillary muscle-chordal level and low papillary-apical level, by using anatomic landmarks for orientation. Interpatient differences existed in the depth of transducer insertion required to obtain short-axis views. The basal left ventricular short-axis views were obtained from the esophagus in some patients, and from a gastric location in others; in others it was uncertain whether the transducer was located in the esophagus or stomach. The primary objective was to obtain short-axis images orthogonal to the left ventricular long axis at three levels identified by internal landmarks. Images that best fulfilled these requirements were taken for analysis, regardless of probe position. At each short-axis level, the transducer was manipulated to obtain images with a circular left ventricular cavity and symmetric wall thickness, evidence of a beam path that was orthogonal to the long axis. In two patients, images that completely satisfied these criteria could not be obtained, so recordings that most closely conformed were selected for analysis. Transesophageal images were recorded on 0.5-in.- (1.27 cm-) videotape for off-line playback and analysis.

Geometric algorithms. Three echocardiographic formulas validated by Wyatt et al. (2) were used to calculate left ventricular volumes from the two-dimensional echographic images. A version of Simpson's rule formula, modified according to Wyatt et al. (2) to apply to short-axis images, was used to predict ventricular volumes as: 

\[ V = \frac{1}{2} (A_1 + A_2) h + A_3 h/2 + \frac{h^3}{6}, \]

where \( V \) = left ventricular volume, \( A_1 \) = short-axis area at the mitral valve level, \( A_2 \) = short-axis area at the papillary muscle level, \( A_3 \) = short-axis area at the apical level and \( h \) = the length of left ventricle + 3 (Fig. 1A).

An area-length formula was also used to estimate left ventricular end-diastolic and end-systolic volumes. Left ventricular volume (V) was calculated as: 

\[ V = \frac{5}{6} A L, \]

where \( V \) = volume, \( A \) = short-axis area at the mitral valve level and \( L \) = length determined from apex to mid-mitral leaflets in the apical four-chamber view (Fig. 1B) (2).

Horizontal and vertical diameters \( D_1 \) and \( D_2 \), respectively) from the short-axis image at the mitral valve plane were used with the four-chamber length measurement to calculate volume (V) based on a diameter-length formula as: 

\[ V = \frac{\pi}{6} D_1 D_2 L, \]

Transesophageal echocardiographic measurements. Two-dimensional transesophageal echocardiographic images were reviewed off-line to identify the end-diastolic (largest left ventricular) and end-systolic (smallest left ventricular) frames, with the most clearly defined endocardial border and least degree of noise and signal dropout in each view. Care was taken to include only those images in which anatomic landmarks such as mitral leaflets and papillary muscles were clearly visualized (Fig. 2, A to C). Echographic areas, diameters and lengths were obtained by using a commercially available computer system with a digitizing pad and graphics overlay (Data Vue, Microsonics). For cross-sectional areas, the outer endocardial border was traced at
Figure 1. Three models used to estimate left ventricular volumes by transesophageal echocardiography. A, Modified Simpson’s rule method using short-axis (SAX) areas taken from mitral valve (MV), papillary muscle (Pap) and apical (Apex) levels, with height \(h\) derived from left ventricular (LV) length (\(L/3\)). B, Area-length method with the short-axis view obtained at the mitral valve level (MV SAX). C, Diameter (diam)-length model using vertical (\(D_1\)) and horizontal (\(D_2\)) diameters obtained from the mitral valve short-axis view. Left ventricular diastolic and systolic volumes (LV vol) were calculated from the formulas as shown.

Each level as previously done (9) for measurements of ventricular mass and using the electrocardiographic (ECG) display and visual inspection of cavity size to define end-diastole and end-systole. The papillary muscles were included as part of the cavity when tracing the area. End-diastolic and end-systolic frames from three cardiac cycles were traced and averaged to obtain area measurements at each short-axis level. Left ventricular length was taken from the mid-mitral anulus to the leading endocardial edge at the ventricular apex (Fig. 2D). Left ventricular length and diameter measurements were also obtained as the mean values of three cardiac cycles for both end-diastole and end-systole. The horizontal and vertical diameters were obtained by measuring orthogonal distances that bisected the left ventricular cavity in the mitral short-axis plane (Fig. 3).

**Angiographic volumes.** Left ventriculography was performed during held inspiration with the patient in the supine position. Injection of 30 to 45 ml of contrast medium at 10 to 15 ml/s was performed by using a pigtail catheter. Cinera-diographic images were obtained with a 9-in. (22.8-cm) field of view and recorded on cine film at 30 frames/s from the 30° right anterior oblique projection. A 20 x 20 cm grid with radiopaque markers was imaged at the mid-chest level to provide calibration for volumes.

*End-diastolic and end-systolic silhouettes* were digitized off-line from the largest and smallest silhouettes available by cineventriculography with use of a commercially available computer and software package (Hewlett-Packard). Left ventricular length measurements were taken from the mid-portion of the mitral anulus to the apex at end-systole and end-diastole. Frames recorded from premature beats and post-premature beats were excluded. Left ventricular (LV) volume was calculated according to: \(LV\) volume = \(8 A_2 L\) (10) and modified for single-plane images by the Kennedy regression equation (11): \(Volume_{RAO}\) (calculated) = 0.81 \(Volume_{RAO}\) (calculated) + 1.9, where \(RAO = right\ anterior\ oblique\ view\).

**Data analysis.** All volumes were reported in ml as mean values ± SD. Ejection fraction (EF) was calculated as: \(EF(%) = (EDV - ESV/EDV) \times 100\) for both imaging techniques, where EDV and ESV are end-diastolic and end-systolic volume, respectively. Left ventricular volumes as determined from two-dimensional and angiographic methods were compared by using linear regression analysis and correlation coefficients were compared by using Z transformations of the r values.

**Results**

Technically adequate four-chamber transesophageal ECGs and cineangiographic studies were obtained in all 36 patients. Optimal short-axis images displaying a round left ventricular cavity of uniform wall thickness at all three levels, indicative of a beam plane perpendicular to the ventricular long axis, were obtained in 34 (94%) of 36 patients. Asymmetric short-axis images were obtained in two patients despite repeated transducer manipulations (Fig. 4). In these latter cases, the short-axis images that most closely conformed to orthogonal were used for volume calculations. There were no complications during or related
Figure 2. Transgastric short-axis (A, B and C) and transesophageal four-chamber (D) images demonstrating methods used to calculate volumes. Short-axis areas were obtained by tracing the endocardial border (white dots) at the mitral valve (A), high papillary-chordal (B) and low papillary-apex (C) levels. Diameter measurements were taken from the mitral valve level. Left ventricular length was measured from the mitral valve to apex as shown (D). Circ = circumference; LA = left atrium; LV = left ventricular; RV = right ventricle; other abbreviations as in Figure 1.

to insertion of the esophageal imaging probe. No hemodynamic changes or changes in clinical status occurred during performance of the transesophageal studies. Interobserver variability was assessed by two reviewers in a subset of seven patients from this study. The mean variability for the two observers for end-diastolic volume was ≤10% for all three methods and was even less for end-systolic volume.

Left ventricular diastolic volumes (Fig. 5). Angiographically determined values for end-diastolic volume ranged from 67 to 528 ml (mean 171.6 ± 90). Two-dimensional
Figure 4. Transgastric short-axis images (A, B and C) from a patient in whom symmetric cross sections of the left ventricular cavity could not be obtained. Although an image plane orthogonal to the long axis was achieved at the mitral valve level (A), short-axis scans at the papillary muscle (B) and apical (C) levels yielded asymmetric tomographic slices despite repeated attempts. Images such as these were encountered in 2 of 36 patients, yet those most closely conforming to the standard views were included in the data analysis. Abbreviations as in Figures 1 and 2.

Figure 5. Linear regression plots comparing end-diastolic volumes (EDV) in ml for Simpson's rule, area-length and diameter-length methods. A, Correlation between Simpson's rule and angiographic (Angio) end-diastolic volumes was good at $r = 0.85$; SEE (see) 42 ml. B, Correlation between transesophageal area-length and angiographic end-diastolic volumes was $r = 0.84$; SEE 46 ml. C, Correlation for transesophageal diameter-length and angiographic end-diastolic volumes was best at $r = 0.88$; SEE 30 ml. Transesophageal echocardiographic volumes were smaller by all methods used ($p < 0.003$ for each).

Echocardiographic estimates of end-diastolic volume using the modified Simpson's formula yielded a range of 39 to 477 ml (mean 128.1 ± 79). The correlation between the angiographic and Simpson's rule method for end-diastolic volume ($y = 0.75x + 0.2$) was $r = 0.85$, with a standard error of the estimate of 42 ml (Fig. 5A). Transesophageal echocardiographic
measurements using the area-length formula yielded end-diastolic volumes that ranged from 43 to 496 ml (mean 137.8 ± 84). The correlation between area-length and angiographic diastolic volumes (y = 0.78x + 4.0) was r = 0.84 and SEE = 46 ml (Fig. 5B). Calculation of end-diastolic volume by the diameter-length formula yielded a range of values from 41 to 373 ml (mean 102.6 ± 62). The correlation of this method compared with angiographic diastolic volume (y = 0.60x − 1.2) was r = 0.88 and the SEE = 30 ml (Fig. 5C). Correlation coefficients were slightly less when the one patient with an extremely large diastolic volume was excluded (r = 0.70 for Simpson’s rule, r = 0.68 for area-length formula and r = 0.76 for diameter-length formula).

Left ventricular end-systolic volumes (Fig. 6). Angiographic measurements of end-systolic volume ranged from 14 to 402 ml (mean 91 ± 74). Estimates of the end-systolic volume using Simpson’s rule and transesophageal echocardiography ranged from 9 to 355 ml (mean 67.3 ± 62). The correlation of Simpson’s rule and angiographic systolic volumes (y = 0.78x − 3.5) was r = 0.94 and the SEE was 22 ml (Fig. 6A). With use of the area-length formula, transesophageal echocardiographically derived estimates of systolic volume ranged from 41 to 496 ml (mean 137.8 ± 74). The correlation of these values with angiographic volumes (y = 0.82x + 0.66) was r = 0.93 and the standard error was 25 ml (Fig. 6B). The diameter-length formula applied to echocardiograms yielded end-systolic volumes that ranged from 10 to 373 ml (mean 75 ± 65). The correlation of these values with angiographic volumes (y = 0.66x − 8.4) was r = 0.95, with an SEE of 17 ml (Fig. 6C). Correlations were r = 0.90 (diameter-length formula) when the one patient with a large systolic volume was excluded from analysis.

Left ventricular ejection fraction (Fig. 7). Measurements of left ventricular ejection fraction derived from angiography ranged from 22% to 80% (mean 51.9 ± 15%). Ejection fraction determined from transesophageal echocardiography using the volumes obtained from the modified Simpson’s rule had a range of 24% to 79% (mean 51.8 ± 15%). The correlation between ejection fraction derived by angiography and echocardiography with the Simpson’s rule method (y = 0.82x + 9.0) was r = 0.85 and the SEE was 8% (Fig. 7A). Application of the area-length formula for left ventricular volumes and ejection fraction by transesophageal echocardiography yielded a range of values from 25% to 78% (mean 49.8 ± 14%). The correlation between area-length and angiographic ejection fraction (y = 0.73x + 12) was r = 0.80 and the SEE was 8.7% (Fig. 7B).

Measurements obtained from the diameter-length formula and transesophageal images showed a range of ejection fraction from 20% to 90% (mean 54.9 ± 17%). The correlation of this method with angiographic ejection fraction (y = 0.88x + 14) was r = 0.73 and the SEE was 11.9% (Fig. 7C).

Measurements of left ventricular length. In the course of performing the transesophageal studies, it was recognized from the appearance of the left ventricular cavity shape that the ventricular long axis may represent a "foreshortened" or oblique scan plane. Therefore, a subsequent analysis was performed to compare the angiographic left ventricular length with transesophageal measurements from apex to base in the four-chamber view.

Diastolic lengths from transesophageal four-chamber...
views ranged from 5.8 to 11.6 cm (mean 7.71 ± 1.2) and angiographic diastolic lengths ranged from 6.9 to 13.3 cm (mean 9.2 ± 1.4). The angiographic values were greater by a mean of 1.56 cm (p < 0.0001); the correlation was only fair at r = 0.55.

Systolic length measurements were also greater by the angiographic technique. The left ventricular systolic length ranged from 2.4 to 10.7 cm (mean 5.7 ± 1.6) by transesophageal two-dimensional echocardiography and from 6.2 to 13.1 cm (mean 8.1 ± 1.6) by ventriculography. The difference was greater for angiographic dimensions by a mean of 2.5 cm (p < 0.0001) with a slightly better correlation (r = 0.78).

Discussion

Left ventricular function has been described (12,13) as a major determinant of prognosis in all types of adult cardiovascular disease. The need for noninvasive methods for evaluating cardiac performance has led to the development of approaches for the prediction of ejection fraction by transthoracic echocardiography. However, the transthoracic window often may not be adequate in critically ill patients and may not be available for monitoring left ventricular function during surgery, whereas transesophageal echocardiography can readily be used in these situations (8,14,15). Therefore, it is of great importance to document the ability of transesophageal imaging to yield estimates of left ventricular volumes and ejection fraction. Our data show that the standard transesophageal and transgastric images can provide values for left ventricular size and global contraction that correlate well with those obtained by angiographic methods.

The three methods of measurement. Previous studies of left ventricular size and function using transesophageal images have employed complicated three-dimensional computer reconstruction from short-axis planes (16) or followed sequential regional changes in short-axis areas during alterations in loading conditions (14,15). In this study, we compared these three standard formulas for estimating volumes based on the assumption of a hemiellipsoid shape of the left ventricle. The geometric algorithms chosen for use in this study have been validated in animal studies (2,17,18) and humans (1-4). Wyatt's modification of Simpson's rule, area-length and diameter-length methods combine the short-axis area or diameter measurements and left ventricular length to estimate volumes. The formulas used in this study were chosen because they require a minimal number of imaging planes and measurements yet utilize the high quality cross-sectional tomograms available from the esophageal and gastric windows to estimate ventricular volumes.

angiographic volume calculation. Ventriculography is a commonly used reference standard for left ventricular volume determination, but it is not without limitations. The area-length formula we used for estimating angiographic volumes from the right anterior oblique ventriculogram is similar to that used for the two-dimensional echocardiographic methods (19). Application of the area-length formula assumes that the left ventricle is a symmetric ellipsoid. Because this is rarely the case, a correction must be made based on an ideal relation between the major and minor diameters (20). For single-plane images, the formula requires that the angiographic length corresponds to the true long axis of the ventricle, whereas the minor-axis measurement is

![Figure 7. Linear regression plots comparing ejection fraction (EF%) from the Simpson's rule, area-length and diameter-length volume calculations taken from transesophageal images with angiography (Angio). A, Simpson's rule model resulted in the best correlation at r = 0.85; SEE (see) of 8%. B, Area-length model yielded r = 0.80; SEE 8.7%. C, Diameter-length model yielded r = 0.73; SEE 11.9%.](image-url)
derived from the length measurement, assuming a prolate ellipsoid shape. Additional corrections are necessary to allow for the overestimation of postmortem volumes by ventriculographic techniques, presumably because of the inclusion of trabeculae, papillary muscles and mitral valve apparatus within the silhouette (21). This method using single-plane ventriculography and area-length volume calculations has been shown to result in an SEE of 9% compared with actual volumes from ventricular casts (20). Several formulas may be used to calculate left ventricular volumes from cineangiography and may provide slightly different measurements. Although use of an algorithm other than the area-length algorithm used in this study might have yielded slightly different results, it is most unlikely that it would alter our major conclusions.

**Comparison of transesophageal echocardiographic and angiographic volumes** (Fig. 5 to 7). The correlation coefficients for comparing angiographic and transesophageal echocardiographic estimates of left ventricular diastolic volumes ranged from $r = 0.84$ for the area-length formula to $r = 0.88$ for the diameter-length method. The SEE was also lowest for the diameter-length technique (30 ml). Despite the good correlations for each method, the transesophageal techniques underestimated end-diastolic volume compared with values obtained with ventriculographic calculations. The difference was greatest for the diameter-length method, with a mean underestimation of 69 ml for the 36 cases compared with 33 ml for the area-length method and 43 ml for Simpson's rule.

The correlation of systolic volumes by transesophageal echocardiography with those from ventriculography ranged from $r = 0.93$ (area-length formula) to $r = 0.95$ (diameter-length formula). The SEE was small for all three formulas, ranging from 17 to 25 ml. Similar to the diastolic volume data, transesophageal algorithms for estimating end-systolic volume produced a smaller volume than that obtained from ventriculography. The diameter-length method yielded the smallest end-systolic volume, resulting in the greatest underestimation compared with cineangiography (mean difference 39 ml, $p < 0.001$). The area-length and Simpson's formulas also resulted in underestimations (16 and 23 ml respectively, $p < 0.002$).

For ejection fraction calculations, the transesophageal echocardiographic approach compared favorably with ventriculographic measurements. The Simpson's rule algorithm was closest, with a mean difference of $-0.1\%$ ($p = \text{NS}$) and SEE of 15%. The area-length formula resulted in a slight underestimation of ejection fraction, with a mean difference of $-2.1\%$ ($p = \text{NS}$) and SEE of 14%. The diameter-length technique resulted in a mean overestimation of +3% and an SEE of 17%. Thus, although all three transesophageal techniques resulted in underestimation of angiographic volumes, this was a systematic error and the methods remained useful for the approximation of ejection fraction.

**Technical factors affecting results.** Several reasons have been proposed to account for the smaller left ventricular volumes by transthoracic echocardiographic calculations compared with values obtained with cineangiographic, radionuclide or cast models (2,5,22,23). The echocardiographic length measurements normally are made from the mitral anulus to the apex, whereas angiographic lengths are often taken from the aortic valve to the apex (4,5). To attempt to minimize these differences in technique, we also used the mitral plane as the base in the right anterior oblique projection in this study. This modification may have altered the appropriateness of using the Kennedy regression formula for correction. However, it is unlikely that this modest modification substantially changed values for left ventricular volumes. Multiple studies (3–6) using other techniques have consistently demonstrated an underestimation of angiographic volumes by echocardiography. Furthermore, use of the shorter angiographic long axis likely minimized the underestimation by echocardiography. Similarly, the papillary muscles are traditionally included as part of the ventricular cavity when systolic and diastolic angiographic silhouettes are traced (21). Although papillary muscles are usually excluded by echocardiography, in this study the left ventricular borders were traced to include the papillary muscles as part of the cavity for both transesophageal and cineangiographic images.

Another source of discrepancy relates to the silhouette format of X-ray imaging and the tomographic or "slice" technique used by echocardiography. Radiographic imaging of the dye-filled ventricular cavity includes the endocardial trabeculations within the outer border and results in a maximal projected area. Conversely, two-dimensional echocardiograms allow the observer to identify the endocardium and invaginations within tomographic imaging planes. Because regional wall motion abnormalities may be missed when using a limited number of image slices, the echocardiographic methods described here may potentially yield an inaccurate assessment of overall ventricular performance in patients with segmental dysfunction.

Despite attempts to correct for methodologic differences, the angiographic volumes were estimated as larger by approximately 25% regardless of the algorithm used. One possible source of error is that the esophageal four-chamber plane may not represent the true long axis of the left ventricle. "Foreshortening" due to an oblique transducer position has been described for this view (24) and may be unavoidable because of limited transducer mobility within the esophageal space. Thus, it appears that underestimation of left ventricular length from base to apex may be a major factor contributing to the smaller volumes obtained by transesophageal echocardiography.

**Technical factors imposed by the constraint of the esophagus and position of the stomach** may influence the ability to obtain optimal images of the left ventricle by transesophageal echocardiography. Thus, foreshortening of the long axis may occur in the four-chamber view, and short-axis views...
may be obtained that are not orthogonal to the ventricular long axis. We utilized internal landmarks in an attempt to record optimal images. However, tangential views were occasionally the only images obtainable, despite vigorous transducer angulation. Similar circumstances are, of course, sometimes encountered with transthoracic echocardiography. Inclusion of the best possible images, as in this study, clearly reflects the typical circumstances encountered clinically. Analysis of the data obtained in this manner demonstrates that transesophageal measures of left ventricular volumes and ejection fraction yield clinically useful estimates of angiographic values.

Entry criteria for this study included patients having sinus rhythm, left ventriculography and transesophageal echocardiography. Although all 36 patients had adequate images for measurement by both techniques, the catheterization and transesophageal studies were not performed simultaneously. The majority of our patients evaluated underwent catheterization several days before transesophageal echocardiography, which was performed just before an operative procedure. Although no interim changes were noted in clinical or hemodynamic status, loading conditions were potentially different in these situations. The underestimation of angiographic ventricular volumes by two-dimensional echocardiography has been previously reported in studies (1-4,22,23) using transthoracic echocardiographic imaging techniques, and we believe that the transesophageal volumes are smaller because of the technical factors described.

Transesophageal echocardiography is a semi-invasive procedure and obviously entails greater risk and discomfort to patients than do transthoracic techniques. Nevertheless, numerous recent reports (7,8,14,15,24) attest to the feasibility and safety of this procedure. However, it is not our purpose to advocate the application of transesophageal echocardiography for the routine calculation of left ventricular volumes and ejection fraction. Rather, the purpose of this study was to determine whether transesophageal images could be utilized to obtain these measurements in patients undergoing this examination for specific diagnostic indications. Our data clearly support the validity of transesophageal echocardiography for this application.

Conclusions. This study demonstrates that standard two-dimensional echocardiographic models can be applied to transesophageal views to predict the angiographic volumes. There is a systematic underestimation of angiographic end-diastolic and end-systolic left ventricular volumes when transesophageal views are used for calculation, which may be due to technical differences in the imaging techniques, compounded by foreshortening in the four-chamber esophageal plane. Each of the three algorithms evaluated gave adequate correlations for volumes. The modified Simpson’s rule and area-length methods gave slightly better correlations for ejection fraction than did the diameter-length model. For practical application, the area-length model may be preferable because it requires fewer measurements and employs a simpler formula.

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