LEFT VENTRICULAR FUNCTION has been assessed by many methods. In the clinical setting, ejection fraction has been shown to be one of the most useful. For example, it is related to prognosis as well as operative risk in patients with coronary artery disease and in those with other forms of heart disease.

The angiographic technique for determination of left ventricular ejection fraction is based on the actual calculation of end-diastolic and end-systolic volumes, using the area-length method of Dodge and associates. These calculations require precise measurements of the distances between the left ventricle, the x-ray tube and image intensifier, and then filming a calibration grid at the level of the left ventricle. Some laboratories omit this measurement of roentgenographic magnification and report an “ejection fraction” based solely on comparison of end-diastolic and end-systolic silhouette areas. Studies have appeared without a description of the method for the determination of ejection fraction. We compared the two techniques of calculating ejection fraction and present a regression curve that allows an accurate and simple determination of ejection fraction without having to take roentgenographic magnification and volume calculation into account.

### Methods

Thirty-degree right anterior oblique (RAO) left ventriculograms of 538 cases from three cardiac catheterization laboratories were reviewed. Patients with coronary artery disease, valvular disease, cardiomyopathies and congenital heart disease were included. The end-diastolic and end-systolic silhouettes were hand-traced.

#### Volume Method

Assuming the ventricle to be ellipsoid, the volume of each silhouette was derived using the formulas of Dodge and associates. Long-axis length (L) was measured from the mid-aortic root to the apex. Area (A) was measured by planimetry and minor axis (D) was calculated as

$$ D = \frac{4A}{\pi L} $$

The volumes (V) were then calculated by

$$ V = \frac{\pi}{6} (D)^2 (L) $$

A grid calibration was used to correct for magnification in the measurements. These volumes were then corrected using the regression equation for RAO cineangiogram of Kennedy and associates:

$$ V_c = 0.81 V + 1.9 $$

Using the final corrected volumes for end-diastole and end-systole, the ejection fraction was calculated as

$$ \frac{\text{end-diastolic volume} - \text{end-systolic volume}}{\text{end-diastolic volume}} \times 100 $$

#### Area Method

The areas of the end-diastolic and end-systolic silhouettes measured by planimetry were used to calculate an ejection fraction as

$$ \frac{\text{end-diastolic area} - \text{end-systolic area}}{\text{end-diastolic area}} \times 100 $$
Statistical Analysis

A nonlinear least-squares regression analysis was performed on the ejection fractions derived from the corrected volumes and the ejection fractions calculated by areas.

Results

Among the 538 left ventriculograms, the end-diastolic volumes were 68–660 ml. The ejection fractions determined by the actual volumes using the area-length method of Dodge et al.\textsuperscript{16}–\textsuperscript{17} ranged from 8–94%. The correlation between ejection fraction determined by volumes and the ejection fraction by the area method is shown in figure 1. The correlation coefficient by linear regression analysis was 0.98 ($p < 0.005$). The relationship between the two methods is best represented by a curvilinear regression line (fig. 1). This line is represented by the equation

$$\text{EF}_v = -0.006 \cdot (\text{EF}_a)^2 + 1.656 \cdot \text{EF}_a + 1.351.$$  

The area method consistently underestimates the ejection fraction as determined by volumes by approximately 15%. For example, if the ejection fraction calculated by comparing the areas of the end-diastolic and end-systolic silhouettes is 30%, the ejection fraction by the volume method is 45% (fig. 2).

Having determined the areas of the end-diastolic and end-systolic silhouettes, an ejection fraction can be calculated. Using the nomogram in figure 2, this ejection fraction can be quickly and accurately converted to that obtained from volumes.

Discussion

Left ventricular function is an important prognostic factor in the natural history of cardiac disease and the assessment of operative risks.\textsuperscript{10–15} Many measurements, such as $V_{\max }$, dP/dt, and $V_{ce}$, have been used to quantitate the systolic function of the left ventricle.\textsuperscript{2,3} Clinically, ejection fraction has been shown to be one of the most useful indexes of left ventricular function.\textsuperscript{6–15}

Exact measurements of the image intensifier and x-ray tube in relation to the left ventricle are required to determine true volumes.\textsuperscript{18} This step is exacting, time-consuming and often only left ventriculograms without grid calibration are available. This has led some laboratories to simply use end-diastolic and end-systolic silhouette areas for calculation of ejection fraction.

In addition to the method presented in this paper, an ejection fraction can be determined from the equation

$$\text{EF} = 1 - \frac{(\text{end-systolic area}^2)}{(\text{end-diastolic area}^2)} \cdot \frac{(\text{diastolic length})}{(\text{systolic length})},$$

which can be derived from the area-length method of Dodge. This ejection fraction is equivalent to that obtained by actual volumes and a magnification factor is not required. The advantage of the method presented in our paper is that an ejection fraction can be obtained quickly from the end-diastolic and end-systolic areas alone using the nomogram in figure 2.

This study illustrates that the area technique provides misleading information if it is compared to standard values in the literature. In addition, the relationship of ejection fractions determined by areas of end-diastole and end-systole to those determined by actual “true” volumes is demonstrated. We have shown that ejection fractions determined by areas

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{Correlation of ejection fraction by volume method of Dodge et al.\textsuperscript{16–17} and the ejection fraction by area method. $n = 538$. $Y = -0.006 \cdot X^2 + 1.656 \cdot X + 1.351$. Estimates of standard errors of the coefficients are 0.0004, 0.037 and 0.719, respectively.}
\end{figure}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure2.png}
\caption{Curvilinear regression line as shown in figure 1 without data points.}
\end{figure}
alone are consistently lower than those calculated using volumes. Calculation of the ejection fraction by areas alone could lead to serious underestimation of left ventricular systolic function, particularly in patients with reduced ejection fraction; e.g., if the ejection fraction by the area method is 20% the ejection fraction by the volume method would be 33%.

A reasonably good linear correlation ($r = 0.98$) exists between the ejection fraction by volume method and that by the area method over the 20–60% range. This can be improved by using the curvilinear regression line (fig. 2). Having determined the areas of the end-diastolic and end-systolic silhouettes, the ejection fraction by “true” volumes can be accurately and quickly determined using the nomogram in figure 2. Thus, comparison to prognostic data in the literature dealing with left ventricular systolic function can be easily made without determining roentgenographic magnification for volume calculations.

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