Measurement of Left Ventricular Volume in the Canine Heart by Biplane Angiocardiography: Accuracy of the Method Using Different Model Analogies

By Miguel E. Sanmarco, M.D., and Stuart H. Bartle, M.D.

ABSTRACT

Casts of the left ventricular cavity were made in 21 canine hearts. Fifty observations were made by means of biplane X-ray films. Left ventricular volume was measured by water displacement and calculated according to six different model analogies. There was good statistical correlation and small error for each of the methods. Method 1, based on the use of the ellipsoid as the reference figure, and using the projected area and the long axis to calculate the transverse diameter, was more accurate than the others. The standard error of estimate with this method was 2.5 ml or approximately 8% at a volume of 30 ml, an average end diastolic volume for a dog weighing 15 kg.

ADDITIONAL KEY WORDS

Simpson’s rule for volume calculation
long and transverse diameters of ventricle
ellipsoid shape of left ventricle
spatial vector calculation
anesthetized dogs

Measurement of left ventricular volume by means of angiocardiographic or indicator dilution techniques has been studied extensively in recent years. In the angiocardiographic technique, ventricular volume is calculated from single or biplane X-ray films of the left ventricle filled with a contrast medium.

Most of the methods which have been used are based on simple analogies with geometric models. It is accepted, in general, that the dimensions, including the volume of a body of any shape can be estimated by a variety of mensuration techniques and mathematical treatments. Precision of measurements in arbitrary models, however, does not apply necessarily to measurements of the capacity of a chamber as variable in configuration and particularly in internal contours as that of the left ventricle. Efforts have been made previously to validate the X-ray method by using casts of the left ventricular chamber as an objective standard. Chapman et al. used phantoms and a cast of one canine heart studied by biplane cineradiography. Gribbe and coworkers used single-plane cineradiography in plaster casts of eight dog hearts and suggested a correction factor which takes into account the space occupied by papillary muscles, chordae tendineae and trabeculae carneae. Bunnell et al. studied by biplane angiography three casts of combined atrium and ventricle from dogs. More recently, Hallerman and associates validated their approach by means of Wood’s metal casts of twelve canine hearts studied by means of a single plane X-ray film. Finally, Dodge et al. and likewise one of the authors have shared in an extensive study of different geometric models and their accuracy in estimating the left ventricular volume of the human heart.

The purpose of this report is to test, in canine hearts, the accuracy of different geometric models for estimating left ventricular volume using biplane X-ray films. In another paper these studies are extended to the intact hearts of dogs and compared with the washout method of estimating volumes.

Angiographic LV volume calculation

Method 3

\[ V = \frac{\pi L D^2 D^1}{6} \]

where \( L = \sqrt{(L^1 \cos \theta)^2 + L^2} \)

\[ r = 0.958 \quad \text{SEE} = 3.6 \]

Method 4

\[ \log V = -0.3256 + 0.8062 \log X \]

where \( X = A^1 \cdot A^1 \)

\[ Y = 1.386 \cdot X - 1.77 \]

\[ r = 0.958 \quad \text{SEE} = 3.6 \]

\[ Y = 1.150 \cdot X + 1.4 \]

\[ r = 0.971 \quad \text{SEE} = 3.0 \]

Figure 2

Plots similar to figure 1 but by methods 3 and 4. For symbols see legend of figure 1.

Plastic casting material. Graded distending pressures were applied to obtain wide variations in ventricular volume. After the casting material had set, most of the cardiac tissue was cut away. The cast was then immersed in a saturated solution of KOH and removed one to three days later when all tissue had been corroded away. The atrioventricular and aortic-ventricular junctions were marked with an encircling wire. The "true volume" of the casts was measured in triplicate by water displacement. The cast was then suspended over a biplane Schonander unit and X-rays were taken in two or three different positions. Two standard projections were obtained in all the casts; one with the long axis parallel to both X-ray films and another with the long axis parallel to the lateral film and at a 45° angle to the anteroposterior film. A third position with the long axis at a 45° angle to both planes was used in eight casts.

To obtain magnification factors, the central X-ray beam was recorded as a small radiopaque mark and used to calculate the object-to-film distance as described by Dodge et al. Linear measurements were made on the X-ray. Area measurements were made in duplicate with a planimeter on a tracing of the ventricular contour.

Each linear measurement was corrected for X-ray distortion by:

\[ L_t = L_p \times f \]

where:  
\( L_t \) = true length  
\( L_p \) = projected length  
\( f \) = magnification factor = \( \frac{H - P}{H} \)  
\( H \) = tube-to-film distance  
\( P \) = object-to-film distance

Area measurements were multiplied by the square of the appropriate magnification factor.

Left ventricular volume was estimated from the appropriate dimensions by six different methods based on simple plane and solid geometry.

The result of each of these computations is called "calculated volume." The first two of these methods are essentially the same as those studied by Dodge et al.\(^5\) the third by Arvidsson\(^6\) and fourth by Chapman et al.\(^1\) Methods 1, 2, and 3 assume that the left ventricular cavity closely resembles an ellipsoid; they differ only in the ways by which the different axes are determined.

Method 1 utilizes the longer of the measured long axes (\( L \)), whether in the frontal or lateral projection. The transverse diameter (\( D \)) is calculated from the area and the length on each projection. Method 2 also uses the longer of the measured long axes. The transverse diameter is measured perpendicular to it, midway between the apex and the aortic valve. Since the projected
ANGIOGRAPHIC LV VOLUME CALCULATION

long axis (corrected for magnification) is an underestimation of the true length unless the axis is parallel to the X-ray, method 3 corrects for the different projections.

Method 4 utilizes the regression formula of Chapman et al., derived from comparing the product of the areas in two planes with the volume determined by a modification of Simpson's rule. Though Simpson's rule was found to be superior to the area products method in measuring the true volume, the latter gave a good approximation (per cent deviation for actual volumes was $1.4 \pm 7.4$ with Simpson's rule and $2.5 \pm 7.8$ with the regression formula). Simpson's rule is too laborious for use without scanning devices.

Method 5 assumes that the volume of an irregular body may be estimated by multiplying its frontal area by its mean anteroposterior thickness.

Method 6 is based on the assumption that the product of the areas of profile of an irregular body, at right angles to each other, bears a constant relationship to the volume. The constant of proportionality was given the arbitrary value of $1/74$. This method is analogous to method 4 but simpler to use.

Results and Discussion

The different dimensions and formulae used are shown in figures 1, 2, and 3 as are the statistical data obtained. All data are given in table 1. It can be seen from the graphs and table 1 that every method except method 6 yielded, in general, overestimates of the true volume. The overestimation, however, appears to be systematic and good coefficients of correlation were obtained by all the model analogies used.

It seems to us that the two most important factors for this overestimation are: first, the volume occupied by papillary muscles, chordae tendineae and trabeculae carneae, and second, the degree of misfit between the model and the true shape of the ventricle. Figure 4 shows coronal sections at 8-mm intervals of three casts in which distending pressures were varied and volumes of 10, 23, and 44 ml were obtained. It illustrates the variability of internal irregularities at different distending pressures. It is clear that at higher volumes the trabeculations are less pronounced and that the ventricle assumes a rounded cross section.
<table>
<thead>
<tr>
<th>Left ventricle no.</th>
<th>True volume ml</th>
<th>Calculated volumes* ml</th>
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<tbody>
<tr>
<td></td>
<td>Method 1</td>
<td>Method 2</td>
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<td>1.</td>
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<td>5.</td>
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<td>6.</td>
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<td>21.</td>
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*First column in each group: long axes parallel to both planes. Second column: apex tilted 45° toward lateral plane. Third column: further tilting 45° away from frontal plane.

Methods:
- Method 1
- Method 2
- Method 3
- Method 4
- Method 5
- Method 6
All methods studied gave approximately similar correlation coefficients. Method 1, however, had the smallest standard error of estimate. Dodge et al.⁵ also found this method the most accurate in their study of human hearts. The standard deviation of the error between the true and the corrected calculated volume (using the corresponding regression equation) expressed as per cent of the true volume, ranged from 14% for method 1 to 24% for method 3. Figure 5 shows that for method 1 the errors were greater at very small volumes (probably not representative of the normal end diastolic volume in the intact dog) and that they were consistently below 15% for volumes greater than 20 ml. It should be emphasized that unless the calculated volumes are corrected by a statistical regression equation, such as those found in this study, they overestimate seriously the true volume of the ventricular cavity.

From the foregoing data it appears that, when the values are corrected, estimates of left ventricular volume, in the dog, can be made with enough accuracy to justify their use in the analysis of volume-dependent phenomena.

References
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