Effect of Filming Projection and Interobserver Variability on Angiographic Biplane Left Ventricular Volume Determination

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SUMMARY Although biplane right anterior oblique-left anterior oblique (RAO/LAO) quantitative left ventricular (LV) angiography is commonly performed, justification for LV volume calculation using the area length method (originally formulated from anteroposterior-lateral (AP/LAT) angiograms) has been limited. To assess whether RAO/LAO and AP/LAT LV volumes are similar when computed by the area length method formula, we performed biplane cine LV angiography in both RAO/LAO and AP/LAT projections in random sequence in 21 patients and four LV models of known volume. LV silhouettes were drawn independently by two trained observers. Calculated angiographic volume of the models correlated almost exactly with their true volume ($r = 0.999$), establishing the absolute accuracy of this system. Rotation of the LV models through 90° of obliquity at 10° increments demonstrated a mean change from true volume of only $-5.4 \pm 0.7\% (p < 0.001)$. In the patient studies, rotation to the 30° RAO/60° LAO position was associated with significant changes in magnitude of biplane areas and long axes, but area length volume estimates were unchanged. Excellent correlation was found between area length calculated AP/LAT and RAO/LAO volumes with $r = 0.90, 0.97$, and 0.91 for end-diastolic volume (EDV), end-systolic volume (ESV) and ejection fraction (EF), respectively. Furthermore, interobserver agreement in volume assessment was excellent, with $r = 0.98, 0.99$, and 0.94 between observers for EDV, ESV, and EF, respectively. Interobserver and inter-method variability for estimates of LV volume and EF ranged from 5–10%.

We conclude that when using RAO/LAO LV angiography, volume calculation by the area length method is justified.

RECENTLY, QUANTITATIVE LEFT VENTRICULAR (LV) angiographic measurements have become important in the evaluation of LV pump performance. In patients with coronary artery disease, it is generally recognized that biplane angiography provides a much more reliable assessment of ventricular performance than single-plane angiography because in such patients, localized wall motion abnormalities may be missed by angiography in any single plane.1,4

Originally, most centers using biplane left ventriculography used the anteroposterior (AP) and lateral (LAT) views. The commonly used area length method for LV volume calculations described by Dodge and associates5 was based on the AP/LAT biplane angiogram. Some investigators prefer to use biplane right and left anterior oblique (RAO/LAO) LV angiography because of theoretically more adequate assessment of segmental wall motion in these planes.1,6,7 However, the few attempts to validate the Dodge area length formula for the calculation of LV volume from these simultaneous biplane RAO/LAO LV angiograms have been limited to patients with normal ventricles.8

A further consideration in LV volume analysis is interobserver variability. Significant interobserver variability occurs in the subjective assessment of LV wall motion by angiography.9,10 If LV biplane volume measurements should show similar variability, the usefulness of these measurements would be compromised.

The purpose of this study was to determine the changes in area length volume measurement introduced by rotation to the RAO/LAO position 1) in a series of LV models, and 2) in a group of patients undergoing diagnostic left ventriculography in both the AP/LAT and RAO/LAO projections. Although such rotation does cause measurable changes in calculated LV volume, the changes are small, only slightly exceeding the magnitude of interobserver variability.

Methods

LV Model Studies

Calibration Study

In order to calibrate our biplane cineangiographic system, we prepared four models with shapes simulating LV chambers, ranging in volume from

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50–235 mm (fig. 1). Models were composed of a mixture of modeling clay and barium sulfate paste and were coated with shellac to impede dehydration shrinkage. True volume of each model was determined by water displacement.

Each model was oriented with its long axis perpendicular to the biplane x-ray beams of a system using two high-resolution, 9-inch input phosphor image intensifiers, joined in a vertical and horizontal relationship above an x-ray table, the top of which had two-dimensional travel in the horizontal plane. To correct for x-ray magnification, the system had two 2 mm diameter lead pellets which were attached to the exterior face of the input phosphor of each image intensifier and positioned 10 cm apart, on opposite sides of the center of the x-ray beam.

Biplane 35 mm cine films obtained from each of the models were projected onto a horizontal surface by an overhead motion analyzer (Vanguard Instrument Cooperation, Melville, NY) and the projected images were then traced with the stylus of a spark-gap digitizing pen (Graf/Pen Science Accessories Corp., Southport, Conn), interfaced to an IBM 1800 computer system. Biplane volume (V) was calculated by the area length equation:

\[ V = 0.849 \cdot L_{\text{max}} \cdot \frac{A_{\text{ap}} \cdot A_{\text{lat}}}{L_{\text{ap}} \cdot L_{\text{lat}}} \]

where \( L_{\text{ap}} \) and \( L_{\text{lat}} \) are the longest measurable axes within the projected silhouettes, corrected for x-ray magnification, and \( L_{\text{max}} \) is the longer of the two; and \( A_{\text{ap}} \) and \( A_{\text{lat}} \) are the areas within the AP and LAT silhouettes, respectively, determined by computerized planimetry and corrected for x-ray magnification.

Rotation Study

Each of the models was placed within a cardboard cylinder (fig. 2) and oriented within this cylinder in a position simulating the anatomical position of the left ventricle within the body. To simulate patient movement from an AP/LAT to an RAO/LAO position, the cylinder was placed in the biplane x-ray field with its long axis perpendicular to the x-ray beams and then rotated clockwise and filmed at 10° increments from 0–90°. Biplane volume at each increment of rotation was calculated according to the area length formula above and compared to the volume at 0° rotation and to the true volume of the model, determined by water displacement.
Patient Study

Twenty-one stable patients undergoing diagnostic coronary and LV angiography for suspicion of coronary artery disease were in the patient study group (fig. 3). All patients underwent both an AP/LAT and a 30° RAO/60° LAO cine left ventriculogram 15 minutes apart. Filming sequence for the two sets of biplane angiograms was prospectively randomized. Filming was done at 60 frames/sec during power injection of 60 ml of sodium and meglumine diatrizoates (Renografin 76) over 3 seconds. A cine event marker and ECG were simultaneously recorded during angiography.

Before each LV angiogram, with the patient supine, baseline measurements were made of heart rate and LV pressure, the latter using a Statham P23G strain gauge (Statham Instruments, Inc, Oxnard, California) and a photographic recorder (Electronics for Medicine DR-8 recorder).

The two sets of LV angiograms per patient were

**Figure 2.** Apparatus for the model rotation study. Each left ventricular model (fig. 1) was secured within a cardboard cylinder in a position approximating that of the left ventricle within the human body. The cylinder, with its long axis perpendicular to anteroposterior (AP) and lateral (LAT) x-ray beams, was then rotated clockwise at 10° increments to simulate patient positioning for RAO/LAO angiography. Biplane filming was performed at each 10° increment of rotation from 0-90°.

**Figure 3.** Patient study design. Biplane left ventricular (LV) angiograms using both the AP/LAT and RAO/LAO methods were obtained in random sequence, and both sets of angiograms were analyzed independently by two observers. This design thus allowed an estimation of both inter-method and inter-observer variability. PT = patient; EDV = end-diastolic volume; ESV = end-systolic volume; EF = ejection fraction.
then analyzed independently by two trained observers — one a physician/angiographer and the other a technician trained in LV angiographic border recognition. Excluded from analysis were angiographic frames exposed during premature contractions or the following cycle. Each observer traced from one cardiac cycle the end-diastolic and end-systolic LV silhouettes, defined, respectively, as the largest and smallest ventricular silhouettes to inspection. Each observer routinely traced the earliest cardiac cycle post-contrast injection showing well-defined ventricular silhouette borders. These silhouettes were digitized as described above in the LV model study, and estimates of long axis, area, end-diastolic volume, end-systolic volume, and ejection fraction were computed. Data from the two observers and from the two ventriculographic methods were then compared. This experimental design thus permitted an assessment of both inter-method variability and interobserver variability in LV volume determination.

Statistics

Continuous data are recorded as mean ± SEM. The paired t test was used to assess differences between paired data. Regression analysis was performed using the least squares method. Absolute differences of estimates of LV volume and ejection fraction were compared using a randomized complete block design.\(^\text{12}\)

Results

LV Model Studies

Calibration Study

For the four LV models, the calculated area length volume correlated almost exactly with the true volume (fig. 4, \(r = 0.999\)), confirming the absolute accuracy of our system of volume analysis.

Rotation Study

When the LV models were rotated within the cylinder, significant increases were found in \(A_{ap}\) and \(L_{ap}\) (fig. 5), and significant decreases occurred in \(A_{lat}\)

\[ \text{VOL} = 0.849 \cdot L_{\text{max}} \cdot A_{ap} \cdot L_{ap} \]

\[ \text{VOL} = 0.849 \cdot L_{\text{max}} \cdot A_{lat} \cdot L_{lat} \]

Figure 4. Absolute accuracy of the biplane volume system. Excellent agreement was observed between true volume (determined by water displacement) and volume calculated by the area length formula (angio volume) for the LV models. Standard error of the estimate was 2.6 ml. Slope and intercept of regression line did not differ significantly from the line of identity.

Figure 5. Changes in area length volume secondary to rotation of left ventricular model. Data from a representative experiment are shown. Although AP area and long axis \((A_{ap} \text{ and } L_{ap})\) increased slightly, and lateral area and long axis \((A_{lat} \text{ and } L_{lat})\) decreased dramatically, calculated volume deviated by less than 10% from control values.
TABLE 1. Comparison of Variables Between First and Second Left Ventricular Angiogram

<table>
<thead>
<tr>
<th>Variable</th>
<th>LV Angio #1</th>
<th>LV Angio #2</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>LVEDP (mm Hg)</td>
<td>10 ± 1</td>
<td>17 ± 2</td>
<td>0.0001</td>
</tr>
<tr>
<td>LVSP (mm Hg)</td>
<td>120 ± 4</td>
<td>126 ± 4</td>
<td>0.05</td>
</tr>
<tr>
<td>HR (min⁻¹)</td>
<td>85 ± 3</td>
<td>84 ± 3</td>
<td>NS</td>
</tr>
<tr>
<td>LV EDV (ml)</td>
<td>185 ± 10</td>
<td>190 ± 10</td>
<td>NS</td>
</tr>
<tr>
<td>LV ESV (ml)</td>
<td>98 ± 10</td>
<td>98 ± 10</td>
<td>NS</td>
</tr>
<tr>
<td>LV EF</td>
<td>0.493 ± 0.027</td>
<td>0.501 ± 0.025</td>
<td>NS</td>
</tr>
</tbody>
</table>

All data are expressed as mean ± SEM. Left ventricular pressure and heart rate were obtained immediately before angiography.

Abbreviations: LV = left ventricular; angiogram; EDP = end-diastolic pressure; SP = systolic pressure; HR = heart rate; EDV = end-diastolic volume; ESV = end-systolic volume; EF = ejection fraction.

and L(lat) compared to control (0° rotation). However L(max) did not change significantly, and calculated area length volume changed by a mean of only 3.3 ± 0.9% (ranging from −1.3 ± 2.4% at 30° rotation to +8.4 ± 1.7% at 70° rotation). The calculated area length volumes of the models at the various increments of obliquity deviated from the true volume by a mean of −5.4 ± 0.7% (p < 0.001) with a range of −13.0–1.6%.

Patient Study

Clinical and Hemodynamic Data

The 21 study patients had a mean age of 48 ± 2 years, and all were males. Incidence of prior myocardial infarction, documented by a typical history and electrocardiographic changes, was as follows: anterior 29% (six of 21), inferior 29% (six of 21), and no infarction 48% (10 of 21). Hemodynamic and angiographic variables for the first and second biplane angiograms are summarized in table 1. Although LV end-diastolic and end-systolic pressures were higher before the second LV angiogram, no significant change was noted in heart rate, end-diastolic volume, end-systolic volume or ejection fraction.

Inter-method Variability

Silhouettes of a representative patient having both AP/LAT and 30° RAO/60° LAO cineangiograms are shown in figure 6. Analysis of each of the components of the area length formula for the AP/LAT LV angiograms versus those of the RAO/LAO angiograms (fig. 7) demonstrated that, although L(max) remained unchanged, RAO area and long axis increased slightly compared to AP. Furthermore, LAO area and long axis decreased slightly compared to LAT. Changes in area and long axis for the RAO and LAO projections were 10–15% and in opposite directions, tending to cancel one another in the overall volume calculation.

Correlations of RAO/LAO and AP/LAT end-diastolic volumes, end-systolic volumes, and ejection fractions were excellent (fig. 8) with r = 0.90, 0.97, and 0.91, respectively. Although in selected patients there were appreciable differences between AP/LAT and RAO/LAO volumes, there was no consistent trend toward volume overestimation or underestimation, so that least squares regression analysis showed no significant deviation from the line of identity.

Interobserver Variability

Interobserver correlations (fig. 9) for end-diastolic volume, end-systolic volume, and ejection fraction were also excellent, with r = 0.98, 0.99 and 0.94, respectively, and no significant deviations from the line of identity. For the 42 biplane angiograms in the 21 patients, the two observers agreed within 10 ml for end-systolic volume in 83% of the cases, within 15 ml for end-diastolic volume in 86% of the cases, and within 0.05 for ejection fraction in 71% of the cases.

Comparison of Variability Between Observers and Methods

Comparison of interobserver and inter-method (AP/LAT vs RAO/LAO) variability (fig. 10) showed that, for volume estimation, the reproducibility (percent agreement) between observers was slightly greater than the reproducibility between methods. Estimates of end-diastolic volume agreed within a mean of 10 ± 2 ml between observers and agreed...
Figure 7. Comparison of areas and long axes in anteroposterior/lateral (AP/LAT) and right and left anterior oblique (RAO/LAO) projections in the 21 patients having angiography by both methods. Small but highly significant changes are observed in all parameters except $L_{\text{max}}$.

Figure 8. Correlation between area length calculation of volume from right and left anterior oblique (RAO/LAO) angiograms and anteroposterior/lateral (AP/LAT) angiograms in 21 patients having angiography by both methods. The line shown is the line of identity in each case because in no instance did the calculated regression line differ significantly from the line of identity. Excellent correlations were observed between the two angiographic methods for end-diastolic volume, end-systolic volume, and ejection fraction with standard errors of the estimate of 22 ml, 12 ml, and 0.05, respectively.
within a mean of $16 \pm 2$ ml between methods ($p < 0.01$). These values correspond to mean variabilities in estimation of end-diastolic volume of 5.3% and 8.5%, respectively. Similarly, estimates of end-systolic volume agreed within a mean of $8 \pm 1$ ml (8.2%) between observers and within $10 \pm 1$ ml (10.2%) between methods ($p < 0.10$). Finally, ejection fraction agreed within a mean of $0.05 \pm 0.01$ (10%)

Figure 9. Correlation of volume calculations between observer (OBS) one and observer two. Again, the lines shown are lines of identity. Correlations were excellent, and standard error of the estimate was 10 ml for end-diastolic volume, 6 ml for end-systolic volume, and 0.04 for ejection fraction.

Figure 10. Comparison of interobserver and inter-method variability. The cumulative frequency distribution of absolute differences (% agreement) between observers and between methods is shown. For example, end-diastolic volume (left panel) differed between observers by no more than 25 ml in 92% of the cases and differed between methods by no more than 25 ml in 81% of the cases. Overall, this analysis showed that volume estimation between observers was slightly more reproducible than between methods. Inter-method and interobserver variability in ejection fraction estimation were similar, however.
between observers and 0.04 ± 0.01 (8%) between methods (NS).

**Discussion**

This study demonstrates, both in LV models and in patients, that LV rotation secondary to RAO/ LAO positioning does not significantly alter volume calculations by the area length method, thus justifying the use of that method in the calculation of RAO/ LAO biplane LV volumes. The study further demonstrates that interobserver and inter-method variability in LV volume assessment is low, ranging from 5–10%.

**Advantages and Disadvantages of Biplane Oblique LV Angiography**

Early studies using biplane left ventriculography predominantly used AP and LAT views for assessment of LV wall motion and volume. Although some centers continue to use AP/LAT views, others prefer to use 30° RAO/60° LAO biplane LV angiography on the premise that such positioning allows more adequate assessment of regional wall motion, particularly regarding the interventricular septum (LAO view). However, no study has objectively demonstrated the superiority of RAO/ LAO ventriculography over AP/LAT ventriculography in the assessment of wall motion. Furthermore, positioning for oblique LV angiography is not completely reproducible from subject to subject or in the same subject. The elongated LV profile in the RAO view may be difficult to capture on the x-ray image intensifier without panning, while the LV in the LAO view, in contrast, is often small, round, and extremely foreshortened (fig. 6). Perhaps the greatest limitation of RAO/ LAO biplane angiography has been the lack of validation for quantitation of left ventricular volume using the area length method.

**Volume Estimates From Biplane Oblique Angiography**

The Dodge area length method for LV volume measurement was initially formulated from AP/LAT LV angiographic data. Since the area length method is basically a semi-empirical approach using the similarity between the LV cavity to an ellipsoidal reference figure, it does not follow a priori that rotation of the ventricle to a 30° RAO/60° LAO position would yield identical volume estimates compared to the AP/LAT. Indeed, Dodge documented that certain (unspecified) rotations of a LV model yielded underestimation of LV volume by as much as 22% using the area length method.

In the present study, we have shown that rotation of LV models through 90° of obliquity results in changes in volume estimates of less than 10%, despite rather dramatic changes in magnitude of areas and long axes in the various projections. Our computerized methodology allowed determination in each instance of the maximal measurable long axis as specified by the area length method (rather than the length from apex to mid-aortic valve). This technical consideration is particularly important in the LAT and LAO views, where the true long axis does not necessarily coincide with the apex to mid-aortic valve length.

Our patient studies (fig. 7) are in agreement with the LV model studies and show that LV volume, as calculated by the area length method, is similar between AP/LAT and RAO/ LAO biplane angiograms, despite significant increases in \(A_{ap}\) and \(L_{ap}\) and significant decreases in \(A_{lat}\) and \(L_{lat}\) when patients are rotated to the 30° RAO/60° LAO position. The magnitude of changes in area and long axes was approximately 10–15% and in opposite directions, tending to cancel in the overall volume calculation. Our patient data, furthermore, showed high correlation between AP/LAT and RAO/ LAO estimates of end-diastolic volume, end-systolic volume, and ejection fraction, with regression lines statistically inseparable from line of identity (fig. 8). We conclude, therefore, that the area length method for clinical estimation of RAO/ LAO LV volumes is justified.

Our findings in 21 patients, 11 of whom had sustained prior myocardial infarction, are similar to the findings in a recent study by Wynne et al., showing agreement between true volume and Dodge area length volume in 11 postmortem casts of normal ventricles filmed in the 30° RAO/60° LAO projection. However, unlike the study by Wynne et al., which showed a 25% variation in calculated area length volume in a single LV cast rotated through 40° of obliquity, our model studies showed a mean volume change of only about 5% with rotation through 90° of obliquity. Thus, we do not believe that precise standardization of the degree of obliquity is necessary for RAO/ LAO volume studies. This point may be of practical importance, since such standardization is difficult in individual patients.

**Interobserver Variability in LV Volume Determination**

Although recent studies have focused on the interobserver variability in interpretation of coronary and LV angiograms, little information is available on interobserver variability in biplane LV volume analysis. The present study demonstrates that acceptable reproducibility in LV biplane volume analysis is possible between two trained observers, one a physician/angiographer and the other a technician with training in LV angiographic border recognition, but without other formal medical training (fig. 9). Thus, the tedious chore of drawing LV silhouettes may be relegated to paramedical personnel, freeing the physician for other duties.

**Interobserver vs Inter-method Variability**

The close correlation between LV volume estimates by the two observers and two methods (figs. 8 and 9) confirms that neither observer nor method has a detectable consistent bias toward volume over- or underestimation. In individual cases, however, there
were appreciable deviations above and below the lines of identity.

To determine if this "scatter" was similar between observers and methods, the cumulative frequency distribution of absolute differences between observers and methods was plotted (fig. 10) as another index of interobserver and inter-method variability. Mean absolute differences between the two observers for volume estimates were significantly less than between the two methods, but this difference (2–3% of total volume) was probably not enough to have practical significance.

Oblique LV Angiography — Clinical Implications

The present study documents that interobserver variability in quantitative biplane LV angiography is low, and that although RAO/LAO positioning can introduce small changes in LV volume measured by the area length method, such changes are small, only slightly exceeding the limits of interobserver variability.

Although it has been proposed that oblique biplane ventriculography often affords better visualization of the interventricular septum than AP/LAT angiography, limitations of oblique biplane ventriculography include the lack of absolute standardization in patient positioning and considerable foreshortening of the left ventricle in the LAO projection. Both of these limitations may be overcome with the availability of cineangiographic apparatus which allow 1) equipment rotation at specified degrees of obliquity about a supine patient, and 2) angulation caudal-cranially to avoid LV foreshortening in the LAO projection. It is possible that such biplane oblique LV angiograms using "angulated" LAO views will provide the ultimate in assessment of both LV wall motion and volume.15–17

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