Objective and Subjective Analysis of Left Ventricular Angiograms

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SUMMARY
In order to determine the reproducibility of analyses of left ventriculograms, 35 cineangiograms were evaluated by four observers, two using standard quantitative techniques to determine ventricular volumes and a newly devised quantitative system to evaluate wall motion and two others using only visual inspection of the angiograms.

Objective analysis repeated by the same observer correlated well for end-diastolic and end-systolic volumes and ejection fraction (r = .98, .99, .99, respectively) and only one of 105 (1%) wall segments were identified differently. Variability in assessments increased when comparisons were made with a second objective observer. Correlation coefficients for the three volumetric parameters were .95, .98, and .95 and there was disagreement in the assessment of 8% of wall segments. Wide variability was present between an objective and two subjective observers in analyses of end-diastolic volumes (r = .63, .64). Regional wall motion was assessed differently in 19% and 27% of segments, respectively. Though the correlation of objectively and subjectively determined ejection fractions was much better than the correlation for volume (r = .92, .84), it was not as good as the correlation between two objective observers. Occasional errors of clinical significance occurred.

We conclude that subjective analysis has a significant error rate and that reproducibility and accuracy of analysis of left ventriculograms require objective analysis.

Left ventricular cineangiography is widely used to determine the nature and severity of cardiac disease and the effects of surgical and pharmacologic interventions on left ventricular function. Quantitative methods for determination of ventricular volumes have been described and their accuracy validated previously. However, the determination of left ventricular function is frequently made by visual inspection of the cineangiogram rather than by application of objective quantitative techniques. This is especially true of assessments of regional wall motion because well established quantitative techniques are not available.

In this study we have examined: 1) the reproducibility of analyses by objective techniques when employed by the same observer; 2) the variation in objective analyses performed by two different observers; 3) the variation of subjective evaluations made by two experienced observers; 4) the variability between assessments made by subjective and objective observers.

Materials and Methods
Thirty-five left ventricular cineangiograms with good opacification, adequate centering of the image and without frequent extrasystoles were chosen for evaluation. There were 23 men and 12 women with a mean age of 47 years. Six patients had no demonstrable cardiac disease, one had an ostium secundum atrial septal defect, and the remaining 28 had significant coronary artery disease demonstrated by coronary arteriography. Uniplane left ventricular cineangiography was obtained in the right anterior oblique position at 60 frames/sec using 30 to 48 ml of meglumine diatrizoate. The injection rate varied from 10 to 15 ml/sec.

Objective evaluation of left ventricular volumes, ejection fractions, and segmental wall movements were made by two observers who traced end-diastolic and end-systolic frames. The largest and subsequent smallest appearing ventricular silhouettes of a beat that did not represent or follow an extrasystole were used in each instance. Volumes for each silhouette were calculated by the area-length method. The extent of magnification which was determined by filming a lead impregnated ruler at the height of the apex of the heart varied from 1.38 to 1.66. Systolic wall motion was assessed using external and internal reference systems as described previously. A segment was called akinetic when the wall did not move during systole and dyskinetic when outward (paradoxical) movement occurred during systole. To assess hypokinesis a line representing the long axis of the ventricle was drawn from the midpoint of the aortic valve to the apex of both the end-diastolic and the end-systolic silhouettes. A perpendicular chord was drawn one-fourth of the way from the apex to the base of both silhouettes, thus dividing the
ANALYZING LV ANGIOGRAMS

The ventricle is divided along its long axis and a chord three-fourths of the distance from the base to the apex. The two apical areas are combined, thus defining three wall segments for evaluation.

The percentage decrease in area for the anterior, inferior and combined apical segments was then determined for each patient. This method of assessing hypokinesis does not require the actual superimposition of the ventricular silhouettes, but has the same effect as superimposing them along the long axis. The normal percentage decrease in area for each segment was established by determining the decrease in area for these segments in seven patients who had neither coronary artery disease nor hemodynamic evidence of left ventricular abnormality. In these patients, the decrease in area of the anterior segment was 48 ± 16% (mean ±1 sd), the apical segment 64 ± 18%, and the inferior segment 40 ± 14%. Hypokinesis was diagnosed if neither akinesis or dyskinesis was present and if the percentage of systolic decrease in area was less than two standard deviations from normal.

Observer 1 analyzed each angiogram twice at intervals ranging from one week to one year without knowing the frame or beat used previously. Observer 2 selected 21 of 35 angiograms at random and analyzed them without knowing the frame or beat analyzed by Observer 1. Both observers noted the frame numbers of each silhouette traced so that it could be determined whether significant variability could be introduced by tracing different beats.

Subjective evaluation of all 35 angiograms was performed by two experienced observers (Observers Y and Z) with extensive experience in an environment which had allowed them to compare their subjective impressions with objective data. These two observers, working independently, estimated end-diastolic volumes and ejection fractions and graded the wall motion in each of the segments as normal, hypokinetic, akinetic, or dyskinetic. Magnification was judged by visual inspection of the framed ruler. Time for the evaluation was not restricted so that multiple viewings of each angiogram could be made.

The reproducibility of objective techniques was evaluated by comparing the two objective assessments of Observer 1 and by comparing the assessment of Observer 1 with the assessment of Observer 2. The reproducibility of subjective techniques was determined by comparing the assessments of Observers Y and Z. Variability between the objective and subjective methods was determined by comparing the assessment of each of the subjective observers with the assessments of Observer 1 (table 1).

### Results

#### Intraobserver Variation

End-diastolic volume (EDV), end-systolic volume (ESV), and ejection fraction (EF) were highly reproducible when measured by the same observer. The mean variation (±SEM) for these three parameters was 4.8 ± .9 ml/m², 4.7 ± 1.4 ml/m², and .021 ± .003 respectively (table 2). Wall motion was assessed identically on both occasions except that one (1%) of 105

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**Figure 1**

The ventricle is divided along its long axis and a chord three-fourths of the distance from the base to the apex. The two apical areas are combined, thus defining three wall segments for evaluation.

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**Table 1**

Synopses of Observations Compared

<table>
<thead>
<tr>
<th>Variation</th>
<th>Observer 1 vs Observer 1</th>
<th>Observer 1 vs Observer 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intraobserver variation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Objective vs objective</td>
<td></td>
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<td>Subjective vs subjective</td>
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<td>Interobserver variation</td>
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<tr>
<td>Objective vs objective</td>
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<td></td>
</tr>
<tr>
<td>Subjective vs subjective</td>
<td></td>
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</tbody>
</table>

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**Figure 2**

A good correlation is shown between two objective observers. There is an apparent systematic tendency for Observer 2 to estimate volumes lower than Observer 1.

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segments judged normal on one determination was judged hypokinetic on another (table 3).

Interobserver Variation

**Objective versus objective.** The variation between the average of two determinations by Observer 1 and the single observation of Observer 2 was greater than intraobserver variation. The variation (mean ± SEM) for end-diastolic volume, end-systolic volume and ejection fraction was 10.8 ± 1.9 ml/m^2, 5.7 ± 0.8 ml/m^2, and 0.09 ± 0.05, respectively (table 2). Figure 2 demonstrates that there was good correlation between the two sets of measurements (r = .93, .98, .95) and also suggests that most of the variation occurred because volumes determined by Observer 2 were systematically smaller than those determined by Observer 1. The variation when the same beat was chosen for analysis is 9.8 ± 1.4 ml/m^2 and when different beats were chosen 11.4 ± 2.1 ml/m^2. There was disagreement in the classification of wall motion for 5 (8%) of 63 segments examined (table 3).

**Subjective versus subjective.** Interobserver variation for the two subjective observers for EDV and EF was 14.7 ± 2.1 ml/m^2 and 0.056 ± 0.005, respectively. The correlation was better for EF than EDV but varied more than data collected by the two objective observers (table 2). There was disagreement in the assessment of 25 (24%) of 105 wall segments (table 4).

**Variation of Subjective and Objective Methods**

Subjective assessment of left ventricular end-diastolic volume by Observers Y and Z varied considerably from the objective assessments made by Observer 1 (table 2). Correlation of volume deter-

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**Table 2**

<table>
<thead>
<tr>
<th></th>
<th>Difference of means</th>
<th>Standard deviation</th>
<th>Range</th>
<th>Mean variance (± SEM)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obs 1 and Obs 1</td>
<td>EDV (ml/m^2)</td>
<td>1.0</td>
<td>7.4</td>
<td>-29 to +12</td>
</tr>
<tr>
<td></td>
<td>ESV (ml/m^2)</td>
<td>.9</td>
<td>4.7</td>
<td>-20 to +7</td>
</tr>
<tr>
<td></td>
<td>EF</td>
<td>.01</td>
<td>.02</td>
<td>-.07 to +.05</td>
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<tr>
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<td>EDV (ml/m^2)</td>
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<td>9.4</td>
<td>-39 to +3</td>
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<tr>
<td></td>
<td>ESV (ml/m^2)</td>
<td>5.4</td>
<td>4.4</td>
<td>-13 to +2</td>
</tr>
<tr>
<td></td>
<td>EF</td>
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<td>.04</td>
<td>-.55 to +.11</td>
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<td>Obs 1 and Obs Y</td>
<td>EDV (ml/m^2)</td>
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<tr>
<td></td>
<td>EF</td>
<td>.03</td>
<td>.06</td>
<td>-.27 to +.08</td>
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<tr>
<td>Obs 1 and Z</td>
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<td>27.1</td>
<td>-113 to +20</td>
</tr>
<tr>
<td></td>
<td>EF</td>
<td>.01</td>
<td>.09</td>
<td>-.19 to +.27</td>
</tr>
<tr>
<td>Obs Y and Obs Z</td>
<td>EDV (ml/m^2)</td>
<td>13</td>
<td>18</td>
<td>-63 to +18</td>
</tr>
<tr>
<td></td>
<td>EF</td>
<td>.02</td>
<td>.08</td>
<td>-.27 to +.15</td>
</tr>
</tbody>
</table>

The difference of the means is the difference of the mean value for the compared groups. The standard deviation quantifies the scatter about these means. Mean variance is the average absolute difference between repeated determinations.

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**Table 3**

<table>
<thead>
<tr>
<th></th>
<th>Observer 1</th>
<th></th>
<th>Observer 2</th>
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<tbody>
<tr>
<td></td>
<td>Normal</td>
<td>Hypokinetic</td>
<td>Akinetic</td>
<td>Dyskinetic</td>
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<tr>
<td>Observer 1</td>
<td>70</td>
<td>1</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Hypokinetic</td>
<td>0</td>
<td>12</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Akinetic</td>
<td>0</td>
<td>0</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>Dyskinetic</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>13</td>
</tr>
</tbody>
</table>

Observer 1

<table>
<thead>
<tr>
<th></th>
<th>Normal</th>
<th>Hypokinetic</th>
<th>Akinetic</th>
<th>Dyskinetic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observer 1</td>
<td>48</td>
<td>2</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Hypokinetic</td>
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<td>1</td>
<td>0</td>
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<td>0</td>
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<tr>
<td>Dyskinetic</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>4</td>
</tr>
</tbody>
</table>

Italicized numbers denote instances of agreement and numbers not italicized instances of disagreement. For quantitation of error rate, akinesis and dyskinesis were considered the same.
The correlation between objective Observer 1 and subjective Observer Y was poor for volume determination but better for estimation of ejection fraction. All volumes greater than 105 ml/m² were underestimated by subjective Observer Y.

The results of correlating Observers 1 and 2 are similar to those of Observers 1 and Y.
Assessments of wall motion and ejection fraction were similar for all four observers in this example though one subjective observer underestimated the ejection fraction.

developed and validated previously. Variation from day to day in these parameters has been shown and quantitated. The variation demonstrated may be attributed to biologic variation or to errors in measurement. This variability would be greater if angiographic studies were performed in close temporal proximity because angiographic contrast material is known to affect ventricular performance and intravascular volume. This study has quantitated the variability in the measurement of left ventricular function by subjective and objective methods by comparing the assessments of different observers examining the same angigram.

Repeated assessments by the same observer at widely variable intervals were highly reproducible. When the second measurement was performed by a different observer the variability increased slightly. This was especially true of absolute volumes and less

A disparity of clinical significance between objective and subjective observers in the estimate of both ejection fraction and wall motion is demonstrated in this example.
true of ejection fraction where systematic errors in end-diastolic and end-systolic volume measurements tend to cancel one another. No significant variability resulted from selection of different beats so the major source of variability arose from tracing of silhouettes. The extent of variation is much greater if subjective assessments are used instead of objective measurements. Subjective observers did well in judgments of ejection fraction although each made errors of judgment with definite clinical implications (fig. 5). The subjective observers did less well in the assessment of absolute end-systolic and end-diastolic volumes probably because this requires the viewer to integrate the visual image and the degree of magnification.

The disagreement between the two subjective observers contrasts with the close agreement of the two objective observers and suggests that the difference between subjective and objective measurements is not systematic but rather due to random variability in the assessments of subjective observers.

Akinesis, hypokinesis, and dyskinesis are easily defined in qualitative terms but several problems become apparent in clinical application. Various reference systems have been proposed for the crucial step of superimposition of end-diastolic and end-systolic silhouettes. It is obvious that the choice of technique for superimposition will influence the determination of segmental wall motion. It is also apparent that the designation of hypokinesis is frequently arbitrary when it is defined only in qualitative terms. Although designations of segment borderlines in our study are arbitrary and more satisfactory systems may be devised, our results demonstrate that subjective evaluation of wall motion is highly variable and that reproducibility in the assessment of wall motion is facilitated by using objective techniques. Precise determinations of the effects of surgical or pharmacologic interventions on wall motion require quantitative analysis and a clear statement regarding the method of superimposition of silhouettes and quantitation of segmental wall motion.

Each observer must be aware of his or her own limitations in the assessment of left ventricular cineangiograms whether objective or subjective techniques are used. Error rates in the assessment of left ventricular function vary from one individual to another but our study demonstrates that error will be minimized if objective techniques are used.

References

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