Observer Agreement in Evaluating Coronary Angiograms

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SUMMARY

The reliability of interpretation of coronary arteriography as a diagnostic tool was investigated in a sub-study of the VA Cooperative Study of Surgical Treatment for Coronary Arterial Occlusive Disease. Twenty-two physicians with varying levels of experience read 13 cine angiograms — blind — on two different occasions.

Analysis of inter- and intraobserver variability showed that angiographic items about which observers were most inconsistent from one reading to the other had the largest interobserver disagreement as well. They were the distal portions of the left anterior descending and left circumflex arteries. Among the items on which there was most consistent agreement — namely, the right main coronary artery and presence of ventricular aneurysm — there was most often agreement between observers as well. When individual readers were evaluated, some observers were far more consistent in their own readings of all the angiographic items than others. This intraobserver agreement in turn correlated fairly well with how often they agreed with the other observers and with how much experience they reported having in reading coronary cineangiograms.

The VA Cooperative Study of Coronary Surgery began in 1968 as a controlled clinical trial of surgical procedures vs medical treatment for coronary patients with severe angina. Originally the study was initiated to evaluate the Vineberg procedure,1 but by 1970 it was evident that the saphenous vein bypass graft operation should be included in the study. The protocol was modified accordingly, and since 1970 about 95% of all operations have been bypass graft operations. Study of implant surgery was completely discontinued in January 1973. The total number of patients in the bypass study is now over 1,000.

The primary endpoint for this study is duration of survival from date of entry into the study. Among the secondary endpoints, subsequent myocardial infarctions and changes in the so-called "quality of life" are considered very important.

The patients in this study are men with histories of stable angina of at least six months' duration who have been on acceptable medical management for at least three months and who have objective evidence of arteriosclerotic heart disease as demonstrated by an abnormal electrocardiogram or a positive exercise test. Before admission into the study, each patient undergoes cardiac catheterization, including a coronary angiogram and ventriculogram. The angiogram must demonstrate a lumen diameter reduced by at least 50% in one or more of the major vessels in order for the patient to qualify for the study. In addition, the vessel must be suitable for grafting, there must be no evidence of ventricular aneurysm, and myocardial contractility must be sufficient to keep surgical risk within a reasonable range. Myocardial contractility is judged by calculation of the ejection fraction and a subjective evaluation of the ventricular function by the angiographer.

In the screening procedure just described, the reading of the angiogram by the angiographer plays an all-important role. Obviously, therefore, one would hope that the interpretation of the angiogram is valid or at least reliable, i.e., that the doctor looking at the film would come to the same conclusion about the absence or presence of abnormality, as well as the degree of it, if he looked at the film on different occasions and, similarly, that if several doctors studied the same film there would be high agreement among them in their interpretive conclusions. At an early stage in the VA Cooperative Study of Coronary Surgery, a special substudy was undertaken to assess the diagnostic reliability of coronary angiography.

Materials and Methods

The design of the substudy was as follows: twenty-two physicians read 13 angiograms independently on two
different occasions, with a time lapse of several months between the duplicate readings. The film numbers were changed before the second round to insure "blind" readings.

Participants and Films
Twenty of the 22 physicians who participated in the substudy were also participants in the main VA Cooperative Study of Surgical Treatment for Coronary Arterial Occlusive Disease. (The other two readers were considered to be experts in the interpretation of coronary angiograms but were not associated with the VA Hospital system.) The films were selected to include a normal angiogram, a range of pathology of coronary arterial disease, and a variety of abnormalities on the ventriculogram. Only films which were of good technical quality according to established standards at that time (1969 and 1970) were selected. The arteriograms came from three different hospitals, but the arteriography had been performed in general in a similar fashion at all three hospitals. The arteriograms were recorded in the right anterior oblique and left anterior oblique views, with multiple injections and cineangiograms often being obtained in each position. No attempts were made to obtain additional views of the proximal LAD by axial projections for suspected lesions of the segment.

Scoring Technique
Figure 1 is a schematic diagram of the coronary cineangiogram used in the substudy as an aid for indicating the location of lesions. Each participant was asked to assess 15 coronary angiographic items: the left main coronary artery, and the proximal third and distal two-thirds portions of five other coronary arteries (the anterior descending, left circumflex, left marginal, right main, and posterior descending). Each artery was assessed according to the degree of lumen diameter reduction on a 0, 1, 2, 3 scale where 0 was

Figure 1
Schematic diagram of coronary arteries.

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normal, 1 was less than 50%, 2 was 51–99%, and three indicated complete occlusion. An additional code, 9, was reserved for inability to judge. The presence of collaterals and of three left ventricular characteristics (size, contractility, and presence of aneurysm) were rated on a 0–1, (present-absent or normal-abnormal) scale. All findings on items were recorded on a standard report form. An estimate of ejection fraction was not requested on the report form used during the early years of the study. Consequently, this item could not be assessed.

For the purposes of most analyses reported in this paper, the 0, 1, 2, 3 scale was converted to one in which 0 or 1 was equal to zero, and 2 or 3 was equal to one. This reduction of the scale necessarily permits a wider range in the magnitude of possible difference between scores for lumen diameter because a difference between a 0 and 1 score might represent the difference between 49 and 51%, or it might represent the difference between 10% and 90%. However, this division has clinical validity because a score of two and above was considered to be an indication for surgery in this study.

Results

Arrangement of the Data

In order to assess interobserver variability for each angiographic item and to evaluate differences between an individual observer's first and second readings of a given film, the data were arranged in matrices. Figure 2 is an example of a set of data subjected to analysis. It represents the proximal part of the left anterior descending artery as judged for each of the 13 films (subjects) by the 22 readers in round one. The scores are dichotomous so that the 0's mean no lesion or mild lesion, and the 1's mean significant abnormalities. N is the number of observers, R is the number of positive findings for films, and P is the proportion of positive findings for the item over all the films. There is a similar set of data for each of the 15 angiographic items and for the two rounds of readings.

Interobserver Variability for the Angiographic Items

Methods of assessing disagreement between observers (i.e., interobserver variability) are reviewed by Fletcher, C. White ("The measurement of agreement among observers when the data are quantal"; unpublished monograph) and Armitage et al., deal specifically with methodology of observer variability applicable to dichotomous (0, 1) data. They describe in particular three useful measures with computational details, the rationale for their use as well as their statistical properties, and the interrelationships of the three.

One convenient measure of observer disagreement is the Standard Deviation Agreement Index (SDAI), which is simply the standard deviation of the numbers of positive findings from subject to subject on a given item. If, for example, in figure 2 the 22 observers all tended to assign 0's and 1's at random for each subject, this would have the effect of equalizing the value of R (the number of positive findings) from subject to subject, resulting in a small dispersion of the R's such as is the case for films 02 and 10. On the other hand, if observers uniformly agree on the item in question, then R would only have the value 0 or 22, that is, dispersion would be wide between the R's. Thus, the standard deviation of the R's may be used as a measure of observers' agreement; the higher the index the greater the agreement among observers, except for the situation where all subjects are found positive or negative by all observers.

Figure 3 shows the relationship between the SDAI and the proportion of positive findings (P) for the 15 coronary angiographic items, for rounds 1 and 2. All values of SDAI — chance expectation, observed values, and 100% agreement — depend strongly on the proportion of positive findings (P) for the item. Consequently, it is of no great value to compare items with very different P values, except perhaps to measure their excess compared to chance expectation. However, it is not even clear that the same excess would be equally important at two different values of P. With this in mind, one can make the general comment that the level of observer agreement for most angiographic items was found to be approximately midway (dotted line) between chance expectation and 100% agreement. Items 10 and 11 (the posterior descending pathology) were too infrequently observed in this series to be assessed. Apart from small numbers of changes, such as improvement in the

\[ P \cdot (1 - P) \]
agreement about the left main artery (item 1) and some decline in agreement for the left anterior descending distal artery (item 3), the two rounds of readings produced very similar results, with a slight general improvement for the second time around. The readings for the right main coronary, both proximal and distal (items 8 and 9), for left ventricular aneurysm (item 15), and for the left main artery (item 1) showed the highest agreement, especially in the second round, while the distal portions of the left anterior descending and left circumflex (items 3 and 5) had the lowest.

Another index which is used in the evaluation of interobserver agreement in judging the presence or absence of a positive sign is the Pairwise Disagreement Index (PDI). Briefly, this index measures the proportion of pairs of observers who disagree on a given item. From $N$, a given number of observers, $N(N - 1)/2$ pairs can be formed, and for a given item (i), $R_i$ ($N - R_i$) observers disagree in their findings; $R_i$ is the number of positive findings for the item. Thus, PDI is equal to $2R_i(N - R_i)/N(N - 1)$. For example, in figure 2, for the item "LAD proximal" on film 001, with $N = 22$ and $R = 6$, the PDI would be $(12 \times 16)/(22 \times 21) = 0.42$. The PDI takes the value 0 when all observers agree; when observers' judgments are evenly divided, that is, when they disagree maximally, the PDI = 0.5. The mean PDI for an item is obtained by averaging the PDIs for that item over the 13 films.

PDI and SDAI are intimately related, so that when one index is given for an item the other can be calculated. Therefore, in analyzing the same set of data, results expressed by SDAI can be expressed equally as well by PDI. However, because of a scale factor, moderate degrees of observer agreement can be more readily exhibited by SDAI; thus the choice of this index in figure 3. On the other hand, PDI is useful for evaluating each item separately within a film or for evaluating the individual observers.

In order to compare quantitatively the interobserver variability results obtained for the 15 angiographic items by the two independent rounds of readings, the items were ranked separately for each round (fig. 4). The rank of an item was determined by first ordering the items within a film according to the PDI values and then calculating the average rank for each item over the 13 films. Figure 4 shows that there was good agreement between the rank ordering ob-

*The high rank for items 10 and 11 is due to the fact that in this set of films there was little or no pathology in the posterior descending artery.

Relationship between the standard deviation agreement index (SDAI) and the proportion of positive findings for 15 coronary angiographic items. Ranking 15 angiographic items based on intraobserver agreement.
EVALUATION OF CORONARY ANGIOGRAMS

<table>
<thead>
<tr>
<th>Angiographic Items</th>
<th>1 Lt Main</th>
<th>2 LAD Prox</th>
<th>3 LAD Dist</th>
<th>4 LAD Prox</th>
<th>5 LAD Dist</th>
<th>6 LAD Prox</th>
<th>7 Marg Prox</th>
<th>8 R Main Prox</th>
<th>9 R Main Dist</th>
<th>10 Post Desc Prox</th>
<th>11 Post Desc Dist</th>
<th>12 Coll</th>
<th>13 LV Size</th>
<th>14 LV Cont</th>
<th>15 LV Aner.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rd. 1 Ranked by inter observer agreement</td>
<td>2 10 12.5 11 15 8.5 7 5 3 4</td>
<td>1 12.5</td>
<td>14 8.5 6</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Rd. 2 Ranked by inter observer agreement</td>
<td>3 9 14 10 12 15 6 5 4 2 1 8 13 11 7</td>
<td></td>
<td></td>
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<td></td>
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</tr>
</tbody>
</table>

Figure 4

The names of the 15 angiographic items are the column headings and the rank for each item is entered in the appropriate column for each of the two sets of readings. Note that item 1 (left main) ranked second in agreement for the first round and item 15 ranked sixth. For the second set of readings, item 1 ranked third and item 15 ranked seventh. Rank correlation for the two sets of readings was measured by Kendall's tau. The correlation of 0.69 is strong.

Intraobserver Variability for the Angiographic Items

By means of 3 × 3 tables for the first and second sets of 0, 1, and 9 scores given by the 22 observers, the intraobserver variability (assessment of disagreement of each observer with himself) was calculated. Figure 5 shows examples of such tables for the item, “presence of collaterals,” in films 10 and 11. Agreement for film 10 was 19/22 and for film 11, 11/22. The total intraobserver agreement for an item is the left-to-right diagonal for the sum of 18 such tables, one table for each of the 13 films. An example of this for the collaterals is shown in figure 6. Agreement was 208/286 or 73% for this item. Among items judged, intraobserver agreement ranged from 92% for the “best” item, the right main proximal, to 63% for the distal portion of the left anterior descending artery.

Figure 7 shows that the rank correlation between ranking the items by intra- and interobserver agreement was reasonably strong (Kendall tau = 0.56) for both rounds. This means that items about which observers had trouble agreeing with themselves also presented difficulties in agreement from observer to observer. In looking for some reasons for the difficulties, among items with sufficiently similar P values, it was not surprising to find that judgments about distal portions of arteries were less reliable than readings of the proximal portions: first, individual interpretations regarding where one draws the line between the proximal one-third and the distal two-thirds may vary; and second, there can be difficulty in visualizing the distal, more attenuated parts of an artery, particularly if there is obstruction or constriction of the proximal portion. It is less easy to explain, however, the poor agreement about the presence or absence of collaterals and about left ventricular size.

Interobserver Agreement for Observers

Another aspect of the data analysis involved

**Collaterals**

ALL FILMS

<table>
<thead>
<tr>
<th>R2.</th>
<th>0</th>
<th>1</th>
<th>9</th>
<th>146</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1.</td>
<td>108</td>
<td>32</td>
<td>6</td>
<td>134</td>
</tr>
<tr>
<td>9</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>6</td>
</tr>
</tbody>
</table>

Figure 6

Intraobserver agreement for “presence of collaterals” for all films.

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calculating indices of interobserver agreement for each individual observer. The 22 observers were ordered from highest to lowest according to how well they agreed with other readers. Again, the PDI was the measure used. The individuals with the highest ranks have the lowest proportion of disagreements for all paired comparisons. Correlation between ranking observers independently for round 1 and round 2 was 0.34. This weak correlation probably occurred because the judgments of some individuals changed much more from round to round than did those of others.

Intraobserver Agreement for Observers

Readers were also ranked on how well they agreed with themselves over the 15 items for the 13 films. Again, 3 × 3 tables were constructed for the Round 1 by Round 2 scores using the 0, 1, 9 scale described earlier. Figure 8 shows one example of such a table for two observers. Observer 15 agreed with himself 12 of 13 times, and observer 17, only 9/13. There was little disagreement by either reader about the 0 category, that is, when there was no abnormality. The higher agreement on negative findings has often been reported. The sum of all left-to-right diagonals pertaining to one observer served as a basis for ranking observers on intraobserver agreement. This score ranged from 91 to 72% among the 22 readers. Of the six best readers, based on agreement with themselves, five were among the six highest for interobserver agreement as well. Those who ranked as the six lowest in intraobserver agreement also ranked low for interobserver agreement. Thus, the observers who had the lowest agreement with the others were also not consistent with themselves, so one could call them poorer readers.

In order to explain some of the above findings, we collected additional information on the level of experience of each observer in terms of the total number of coronary angiograms which he or she had reviewed up to the time of the study. The results showed that of the seven most experienced observers at the time of this substudy (defined as having read 700–1000 films) five also ranked among the best on intraobserver agreement; one was eighth and the other was fourteenth of the 22. Among the nine readers with the least experience (having read 50–200 films), six were also among the least consistent readers. Correlation between ranking by experience and by intraobserver variability was reasonably strong (Kendall's tau = 0.44). A composite measure that included intra- and interobserver agreement was therefore constructed to allow for a more complete evaluation of the observers' overall reliability.

### Figure 7

**Ranking 15 angiographic items based on inter- and intraobserver agreement.**

### Figure 8

**Intraobserver agreement for one item, two observers.**

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interobserver agreement ratings, calculated for each observer, separated according to the observer's field of specialization, showed that cardiologists did only a little better than surgeons. The difference was not significant and there were twice as many cardiologists among the readers as surgeons. There were no radiologists among the observers.

Discussion

The usefulness of studying interobserver variability is limited in the absence of objective outside sources of validation such as autopsy findings. Ordinarily, the rank of an observer on how well he agrees with the others would not justify inference about how good a reader he may be. The one who disagrees with many observers (high PDI) can easily be the one who is right. However, the strength of this particular study is derived from the addition of the second round of readings. This design allowed not only for replication of the measurements of interobserver agreement, and thus, confirmation of the results obtained from the first set of observations, but also added the possibility for another independent measure of reliability, that of the intraobserver agreement. This measure expresses the percentage agreement that observers have with their own previously formed judgments. Although high intra- and interobserver agreement does not assure that the observer is right in his judgment, it is certain that he could hardly be right if he disagrees often with himself. Similarly, a diagnostic item which repeatedly presents difficulties in intra- and interobserver agreement would not be a good one to select as a basis for important clinical decisions.

In view of the considerable inter- and intraobserver variability which was found in the above study, it seems clear that future collaborative or epidemiologic studies which plan to utilize data obtained by coronary angiography should keep this variability in mind when designing the study. Procedures in the cooperating clinical centers should be as uniform as possible. The establishment of a central reading laboratory with its own quality control procedures, similar to those often used for ECG interpretation, would be more desirable.

Short of this ideal situation, the present VA Cooperative Study of coronary surgery began an angiographic review program under the leadership of a specially appointed committee. As part of this program, new angiographic report forms were designed that provided for more specific descriptions of graftability of vessels, estimation of ejection fraction, and other additional details of the ventriculographic studies and collateral circulation and its sources. Illustrations were attached to the revised forms to indicate specifically the site of division of the artery into its proximal and distal portions. Disagreements between the original and the second readings of an angiogram that leave the eligibility of a patient for entry into the study in doubt will subsequently be resolved by the common judgment of a panel of experts. In addition to these measures, it would be appropriate to carry out more observer variability studies on present-day coronary angiography. Only findings of several similar investigations would allow generalization about the relative reliabilities of judging pathology in the various locations and functions revealed by the angiogram.

Finally, it must be said that while errors in diagnosis by coronary angiography have been found to be very real and need to be acknowledged and further investigated, they are not different from errors found in other areas of medical diagnosis where human judgment must ultimately be translated into quantitative terms. The interpretation of chest X-rays, ECGs, physical diagnosis, history taking, and histopathological examination are areas that pose similar problems. While the aim of studying observer variability is obviously to recognize and continuously attempt to eliminate the sources of error, as long as complexities of human judgment remain the basis for the final numerical values, some irreducible minimum variation will always have to be accepted. This, after all, is the element that keeps medical diagnosis still somewhat in the realm of "art."

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Appendix
This work was carried out as a Substudy under the auspices of the VA Cooperative Study of Surgery for Coronary Arterial Occlusive Disease.

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