Accuracy and Reliability of Quantitative Measurement of Coronary Arterial Stenosis by Videodensitometry on Coronary Angiogram

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SUMMARY

This study was undertaken to investigate the accuracy and reliability of videodensitometry (VDM) in measuring the magnitude of coronary arterial stenosis on coronary angiogram (CAG). CAG taken after administration of sublingual nitroglycerin was analyzed with VDM (XR-70 Coronary Analyzer, Vanguard). The magnitude of stenosis in coronary segments with four different classes of stenosis was consecutively measured 10 times by the same observer, and the values were 89.0±1.4, 70.9±2.1, 59.5±2.5, and 22.8±3.4%. The coefficients of variation (CVs), indicating intraobserver variability, were low for severe to moderate lesions (1.6, 2.9, and 4.3%, respectively), but was higher for low-grade lesions (14.8%). When the same lesions were measured by 2 observers, the measurements were highly correlated (r=0.971, p<0.01). The results of VDM were consistent with those of conventional gross examination for moderate to severe lesions, and the discrepancy was mainly found in low-grade lesions. The magnitude of stenosis of the same lesion was measured from the right and the left anterior oblique views, and the cineangle was found not to affect the results of VDM. Moreover, cardiac cycle did not affect the videodensitometric measurements of % area stenosis. In order to further investigate the accuracy of VDM, the magnitude of stenosis was measured in nine phantom arteries, and the value measured by VDM significantly correlated with the actual stenosis (r=0.969, p<0.001). These results indicate that the values of coronary arterial stenosis on CAG measured by VDM are accurate and clinically acceptable, even though variability is somewhat high for low grade lesions. VDM may be useful for evaluation of the outcome of PTCA and the anti-atherogenic action of some agents.

Key Words:  
Coronary angiography
CORONARY angiography (CAG) has been widely used as a standard diagnostic technique for the detection of coronary artery stenosis. The magnitude of coronary artery stenosis has been semi-quantitatively diagnosed by gross examination. This has been sufficient for clinical purposes such as for making the decision to perform percutaneous transluminal coronary angioplasty (PTCA) or coronary artery bypass surgery. However, the demand for quantitative measurement of the magnitude of coronary arterial stenosis has recently increased for use in determining the efficacy and outcome of PTCA, and in investigating whether some therapeutic agents exert an anti-atherogenic action.

The methods for the measurement of the magnitude of coronary arterial stenosis are divided into two categories according to the fundamental principle. One is to compute the luminal diameter and % area stenosis of the stenotic coronary artery segment based on the edge detection method. The other is videodensitometry in which the image of the coronary artery generated by contrast media is transformed into the strength of a videosignal. A simple and convenient instrument for videodensitometric measurement of coronary artery stenosis has recently been developed. In this study, we tested the accuracy and reliability of the method to investigate the clinical usefulness of videodensitometry in the quantitative measurement of coronary arterial stenosis.

**Materials and Methods**

**Coronary angiography**

CAG was performed by using either the Judkins method or the Sones method. It was taken from multiple angles of view both in the right anterior oblique (RAO) and in the left anterior oblique (LAO) positions after sublingual administration of 0.3 mg of nitroglycerine, and was recorded on 35 mm cinefilm at a speed of 60 frames per second.

**Videodensitometry**

The cinefilm of CAG was mounted on a projector (XR-35, Vanguard Instruments, Melville, NY, USA), which was connected to a videodensitometric analyzer (XR-70 Coronary Analyzer, Vanguard). The cineframe suitable for the measurement of coronary arterial stenosis was selected by experienced cardiologists from specific points of view. These included projected angles and the signal/noise ratio. Moreover, the cineframe in which the images of other arteries and the catheter did not fall into the region of interest (ROI) were selected.
The principle underlying the measurement of coronary arterial stenosis has been described elsewhere. Briefly, however, the selected cineframe is digitized and displayed on a CRT monitor. The intensity of transmitted light through the cineframe is transformed into the intensity of the videosignal by a built-in computer system, and two points across the site to be measured are assigned with a mouse driver. The computer system scans across the points 5 times and computes the distribution of intensity of the videosignal across the site to be measured. The videosignal was measured for $3 \times 3$ pixels at each point across the site to be measured, and the mean value was considered to be a background signal for each point. The area under the curve above background videosignals, which indicates the sum of the videosignal, at the stenotic site is compared to that at the normal site just proximal to the stenotic site, and the ratio indicates the % area stenosis of the stenotic lesion (Fig. 1).

**Intraobserver variability of videodensitometry**

The four classes of coronary lesions with mild, moderate and severe stenosis on CAG from 3 patients were selected as ROIs to determine the intraobserver variability of the videodensitometric measurement of coronary arterial stenosis. The magnitude of stenosis of each lesion was measured 10 times by videodensitometry, and the mean and the standard deviation (SD) were calculated. The coefficient of variation (CV) was calculated as the $(SD/\text{Mean}) \times 100$ (%) for each class of lesion.
Correlation between 2 observers
The magnitude of stenosis was measured by 2 observers for 24 ROIs having various magnitudes of stenosis on the same cineframe of CAG from 7 patients, and the correlation was evaluated.

Relationship between videodensitometry and conventional gross examination
A total of 40 ROIs were classified into four categories of stenosis, that is, 0–25%, 25–50%, 50–75%, and 75–99% by a conventional gross examination (n=10 for each category). Afterwards, the magnitude of stenosis was measured by videodensitometry for each ROI, and the measured values were investigated to determine whether or not they fell within the categories.

Effect of cineangle on videodensitometric measurements
The effect of cineangle on the results of videodensitometric measurement was evaluated. A total of 18 ROIs on CAG were selected from 7 patients. The magnitude of stenosis was measured both in the RAO view and in the LAO view, and the results from each view were compared.

Effect of cardiac cycle on videodensitometric measurements
The effect of cardiac cycle on the results of videodensitometric measurements was investigated on three classes of the magnitude of stenosis (n=10 for each class). The cineframe at four points during cardiac cycle, the initiation of P wave, the peak of R wave, the end of T wave and the mid-point of the latter two points, were selected by using electrocardiograms taken simultaneously with CAG and printed onto each cineframe. The % area stenoses of the four points were measured for each stenosis on CAG.

Videodensitometric measurement of stenosis in phantom arteries
We performed a study using phantom arteries to examine the accuracy of videodensitometric measurement. An eccentric stenosis was made by using the silicon bond in a vinyl tube having a 1-mm thickness and a 3-mm internal diameter. This was considered to be a phantom model for the coronary artery with stenosis. Contrast medium (Iopamiron 370, Nihon Schering) was placed into the phantom artery, which was then horizontally placed in a water tank at a height of 10 cm. The cinefilming was conducted at a speed of 60 frames per second with the vertical application of X-ray beams to the phantom artery. The magnitude of stenosis on the cinefilm was measured by videodensitometry. The phantom artery was dissected at the site of the
greatest stenosis, and the actual stenosis was determined by measuring the
stenotic and the non-stenotic area with a X-Y digitizer.

**Statistics**

The relationship between the two resulting categories of data was an-
alyzed by calculating Pearson's coefficient of correlation. A p value of less
than 0.05 was considered to be statistically significant. All data are pre-
sented in the text and figures as the means±SEM.

**Results**

**Intraobserver variability of videodensitometry**

The magnitude of stenosis of coronary segments in four different classes
of stenosis were measured to be 89.0±1.4, 70.9±2.1, 59.5±2.5, and 22.8±
3.4%. The CV values, calculated from these results, were low for severe to
moderate lesions (1.6, 2.9, and 4.3%, respectively). The CV value for the
low grade lesions was, however, higher (14.8%).
Correlation between 2 observers

Figure 2 shows the correlation of two values for an identical lesion obtained by 2 observers. The values were significantly correlated ($r=0.971$, $n=24$, $p<0.01$), and the two values on the same lesion were almost identical.

Relationship between videodensitometry and a conventional gross examination

Figure 3 shows the relationship between the measured values by videodensitometry and the four categories of stenosis classified by a conventional gross examination. The results for coronary segments having more than 25% stenosis were comparable. The discrepancy was mainly found in the lesions having less than 25% stenosis, and results from a gross examination were found

Fig. 3. The relationship between values measured by videodensitometry and four categories classified by conventional gross examination. Forty coronary lesions were classified into four categories (0–25, 25–50, 50–75 and 75–99%) by gross examination, and then the magnitude of stenosis was measured for each lesion by videodensitometry. The range indicated by the dotted frames corresponds to the magnitude of stenosis for each category. $S=\text{magnitude of stenosis.}$
to underestimate the magnitude of stenosis compared to those derived by videodensitometry.

**Effect of cineangle on videodensitometric measurements**

Figure 4 shows the effect of cineangle on the videodensitometric measurement of the magnitude of coronary arterial stenosis. When the magnitudes of stenosis of the same lesions were measured both in the RAO view and in the LAO view, the results were significantly correlated (r=0.918, n=18, p<0.01).

**Effect of cardiac cycle on videodensitometric measurements**

As shown in Fig. 5, no significant changes were observed in % area stenosis during the cardiac cycle for three classes of the magnitude of stenosis.

**Videodensitometric measurement of stenosis in phantom arteries**

As shown in Fig. 6, the values of videodensitometric measurement in phantom arteries significantly correlated with the actual stenosis (r=0.969, n=9, p<0.01). The correlation equation was calculated as y=0.902 x+

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![Fig. 4](image_url)

Fig. 4. The effect of cineangle on the videodensitometric measurement of the magnitude of stenosis. RAO view=the right anterior oblique view; LAO view=the left anterior oblique view. ●=the left anterior descending artery; ○=the left circumflex artery; □=the right coronary artery. The solid line indicates a regression line, while the dotted line represents y=x.
Fig. 5. The effect of cardiac cycle on the videodensitometric measurement of the magnitude of stenosis for three classes of lesions with mild to severe stenosis. EKG=electrocardiogram.

9.68, where x denotes the videodensitometric measurement and y denotes the actual stenosis.

**DISCUSSION**

In the present study, we examined the usefulness of videodensitometry to measure the magnitude of coronary arterial stenosis on CAG. In videodensitometry, the concentration of the contrast medium at the objective site to be measured is converted to the intensity of videosignals, and the concentration of the contrast medium can be considered to reflect the cross-sectional area of the lumen of the coronary artery rather than the luminal diameter. The luminal cross-sectional area is well known to be a major determinant of coronary flow, and is clinically more important than the luminal diameter.

In the present study, the intraobserver variability in videodensitometry was found to be small. The results obtained by 2 observers were almost iden-
Fig. 6. The relationship between the value of stenosis measured by videodensitometry and the actual stenosis in nine phantom arteries. The solid line represents the regression line, while the dotted line represents $y=x$.

tical, indicating that interobserver variability is also minimum. These results clearly indicate that the reproducibility of videodensitometric measurements is excellent. However, intraobserver variability was somewhat higher for the coronary lesions with mild stenosis than for those with moderate to severe stenosis. Moreover, the discrepancy between videodensitometry and a conventional gross examination was mainly found in the lesions having less than 25% stenosis. The higher variability in measuring mild stenosis might arise from the higher variability in manually assigning two points across the site to be measured with a mouse driver. Further development of a computing system for videodensitometry might be necessary to improve this point.

Since an atherosclerotic plaque usually develops in an eccentric fashion, the luminal diameter of the stenotic site differs depending on the cineangle in most cases. This might prevent the accurate measurement of coronary arterial stenosis using luminal diameter as described by other investigators.\textsuperscript{1,4} The videodensitometric measurement, however, is expected to be unaffected by the cineangle based on the theoretical background of the method. In the present study, we confirmed that the magnitude of stenosis of the same lesion measured both in the RAO view and in the LAO view was highly correlated. Videodensitometry might be superior to other methods in which the edge of coronary arterial stenosis is determined either manually\textsuperscript{1} or
automatically,\textsuperscript{31,32} and the magnitude of stenosis is calculated based on the luminal diameter. Serruys et al\textsuperscript{4} pointed out that multiple cineangles are necessary for the method to accurately measure coronary arterial stenosis. Furthermore, edge detection might be difficult in lesions with severe stenosis because the contrast generated by the contrast medium may often be insufficient because of the limited coronary flow. In the present study, the variability of the measured values was somewhat greater, although the correlation was significantly high. This might arise from the fact that vertical application of the X-ray beam to the stenotic site, which is essential for accurate measurement by videodensitometry, is sometimes difficult, especially in the LAO view. To minimize this, the cineangle should be so contrived that the X-ray beam is vertically applied to the stenotic site.

Another important finding in the present study is that the measured \% area stenosis was constant during the cardiac cycle. The result indicates that the videodensitometric measurement can be performed at any point during the cardiac cycle, and that this may facilitate videodensitometric analysis.

In the present study using phantom models of coronary arteries with stenosis, the values measured by videodensitometry were very similar to the actual measurements. This clearly indicates that the videodensitometric measurement of coronary arterial stenosis on CAG is accurate. Nichols et al\textsuperscript{6} reported that videodensitometric measurements were also consistent with the actual coronary arterial stenosis obtained at autopsy.

There exist some technical limitations in videodensitometry. First, the accurate measurement of stenosis is theoretically impossible when the image of another coronary branch falls on the site to be measured. To avoid this, the site to be measured should be well separated from the other coronary arteries when CAG is taken. Second, the value of the \% area stenosis may be varied by the location of the reference point because the \% area stenosis is calculated on the assumption that the area across the reference point would be normal. Third, a large difference in background videosignals between both sides and that between normal and stenotic segments might affect calculation of the \% area stenosis. To minimize the effect, videodensitometry should be done at points with similar levels of background signals. Further development of technology for videodensitometry might improve these limitations.

In conclusion, the values of coronary arterial stenosis on CAG measured by videodensitometry are clinically acceptable, even though some limitations have been elucidated. Videodensitometry may be a useful tool for quantitatively evaluating the course of coronary arterial stenosis.
REFERENCES


