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Original Studies

Variabilities in Measurement of Coronary Arterial Dimensions Resulting From Variations in Cineframe Selection

J.H.C. Reiber, PhD, P. van Eldik-Helleman, N. Visser-Akkerman, C.J. Kooijman, MSc, and P.W. Serruys, MD

To quantitatively analyze a coronary arterial segment from a cineangiogram, an end-diastolic or neighboring cineframe is usually selected, such that a possibly existing coronary lesion is visualized optimally, as judged by the cardiologist. However, different cardiologists may select different (although usually neighboring) frames, even when following the same selection criteria. It is also possible that the frames are selected from different cardiac cycles. In this study the effects of such phase shifts on the reproducibility of the quantitative measurements were studied.

In a total of 38 consecutive patient films obtained at a filmspeed of 25 frames/sec, the frame 0 demonstrating the severity of a lesion optimally, as judged by a senior cardiologist, the three preceding frames, the three following frames and one frame exactly one cycle prior to or following frame 0 were selected; frame 0 was always chosen in the end-diastolic phase of the cardiac cycle. In each film one coronary arterial segment with a focal lesion was analyzed quantitatively in these eight frames with the Cardiovascular Angiography Analysis System (CAAS).

No significant differences were found in the mean difference and the standard deviations of the differences (variabilities) in the obstruction diameter, interpolated reference diameter, percent diameter stenosis, extent of the obstruction and area of atherosclerotic plaque obtained in the various frames with respect to frame 0. Therefore, it may be concluded that the selection of a cineframe for quantitative analysis in the end-diastolic phase of the cardiac cycle is not very critical; in other words, the obstruction measurements are not time-dependent for frames in the end-diastolic phase. It is argued that the quality of mixing of the contrast agent in the arterial segment is a major source of the observed variations; filling artefacts are potentially present in each of the selected frames.

Key words: arteriosclerosis, coronary; cineangiography; computers, digital; coronary vessels

INTRODUCTION

Quantitation of coronary arterial dimensions from cineangiograms has found increasing interest in the cardiological community. For the assessment of the efficacy of therapeutic procedures in the catheterization laboratory (e.g., percutaneous transluminal coronary angioplasty (PTCA), thrombolysis, etc.) [1–6], of the effects of vasoactive drugs [7–9], or of the effects of interventions on the regression or progression of coronary artery disease [10], quantitation of the arterial dimensions is absolutely necessary.

It has been demonstrated that the use of a caliper for the quantitation does not enhance either the intra- or the inter-observer agreement, compared with the conventional visual interpretation (eyeball method) [11]. On the other hand, we have shown that with automated edge-detection techniques, the coronary dimensions can be quantitated very reliably and reproducibly [12]. The variability of the data-analysis procedure in the measurement of absolute dimensions was found to be better than 0.10 mm; for the percent diameter stenosis by the interpolated technique, better than 3.94%.

Usually, an end-diastolic cineframe is selected for the quantitative analysis of a coronary obstruction. However, if the obstruction is not optimally visible in this particular

From the Thoraxcenter, Erasmus University and University Hospital, Dijkzigt, Rotterdam, The Netherlands.

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Address reprint requests to Dr. Johan H.C. Reiber, Laboratory for Clinical and Experimental Image Processing, Erasmus University, C.V.R., EE 2328, P.O. Box 1738, 3000 DR Rotterdam, The Netherlands.

frame, for example, because of overlap with an other vessel, a neighboring frame in the sequence may be selected. Also, an aortic pressure signal or ECG-marker on the cinefilm may not be available for the optimal selection of the end-diastolic frame; as a result, the visually selected cineframe may not be the true end-diastolic frame.

In addition, different cardiologists may select different (although usually neighboring) frames, even when following the same selection criteria. It is also possible that the frames would be selected from different cardiac cycles. This uncertainty in the frame selection process raises the question, what the effect may be on the quantitative results of selecting a cineframe at another point in time in the cardiac cycle. Theoretically, there are many variables that may influence the measurement of the arterial dimensions from cinefilm [12,13]. Spears et al. have found that a particular variable of practical importance, the contrast medium concentration, has a statistically significant effect on these measurements [14]. To reduce the variability from quantum mottle, film grain, inhomogeneities of contrast medium concentration, etc., they propose that at least 5 to 10 frames from a single injection should be analyzed and the measurements averaged.

The uncertainty in the frame selection previously mentioned is also present when corresponding frames in pre- and postintervention angiographic studies must be selected. Selzer et al. have also found that the process of matching end-diastolic frames is more difficult than anticipated, and they have modified the analysis procedure to allow segment matching with frames corresponding to other parts of the heart cycle [15]. However, they concluded that a major improvement in measurement variability can be achieved simply by measuring these quantities on two or more sequential frames and then averaging the results. A major cause for the frame-to-frame variabilities was found to be incomplete contrast mixing.

In this study we were interested in determining the measurement variability in the obstructive arterial dimensions if different frames would be proposed for the quantitative analysis in the end-diastolic phase of the cardiac cycle. We assume that the two images to be compared do not differ by more than 3 cineframes. In addition, we studied the variability in the measurements if the two frames were selected in two subsequent cardiac cycles at exactly the same phase in the cycle. Multiframe averaging was not applied in our study.

METHODS

The cinefilms were analyzed with the Cardiovascular Angiography Analysis System (CAAS), which has been described in detail elsewhere [12,16,17]. Eleven of the total of 38 cinefilms were analyzed with the Research CAAS, whereas the other 27 cinefilms were analyzed with the commercial version of the CAAS, the Pie Data[1] CAAS. The hardware of the two systems is different, but the application software is exactly identical.

The research CAAS consists of a second generation cinevideo converter (CIVICO III), a VTE[2] image digitizer and display memory, a PDP 11/44 computer (RSX-llM Operating System) with terminal and writing tablet, and the clinical-application software packages. By means of a computer-controlled film-guiding system, projection lens, and a high-resolution 1-inch Pasecon video camera, any region of interest in a cineframe can be selected on the CIVICO III with the appropriate optical magnification (ranging from 0.7 to 4 in steps of $\sqrt{2}$) [18]. The light source consists of three light-emitting diodes (LEDs) with a narrow light spectrum; the emitted amount of light can be linearly adjusted. A user-controlled, motor-driven diaphragm and automated light control system further provide for optimal image quality in the selected region of interest. The resulting video signal is then digitized in the VTE image processor at a resolution of 512 $\times$ 512 $\times$ 8 bits with a standard 15 MHz video A/D converter.

The Pie Data CAAS consists of five basic components: a specially constructed cinedigitizer, a VIP 500 video image processor, an LSI 11/73 host computer (RSX-llM+ Operating System) with terminal, a writing tablet, and the same clinical-application software packages as mentioned for the research CAAS. A block diagram of the system is shown in Figure 1. The cineframe digitizer consists of a standard Tagarno 35CX cineprojector modified with a specially developed optical chain with monochromatic light source and a high-resolution CCD digital camera. Any 6.9 mm $\times$ 6.9 mm area in a selected cineframe (18 $\times$ 24 mm) can be digitized by the CCD camera with a resolution of 512 $\times$ 512 pixels and 8 bits of grey levels, stored in the video image processor, and analyzed by the host computer. This means that the entire cineframe of size 18 mm $\times$ 24 mm can be digitized at a resolution of 1330 $\times$ 1770 pixels.

To analyze the dimensions of a coronary arterial segment quantitatively, the following steps need to be performed by the application software packages: 1) computation of the calibration factor on the basis of the contrast catheter; 2) automated boundary detection of the arterial segment; 3) computation of the diameter function from the detected and pincushion-corrected contour po-

[1]Pie Medical B.V., Maastricht, the Netherlands.

[2]VTE Digitalvideo, Braunschweig, Germany.

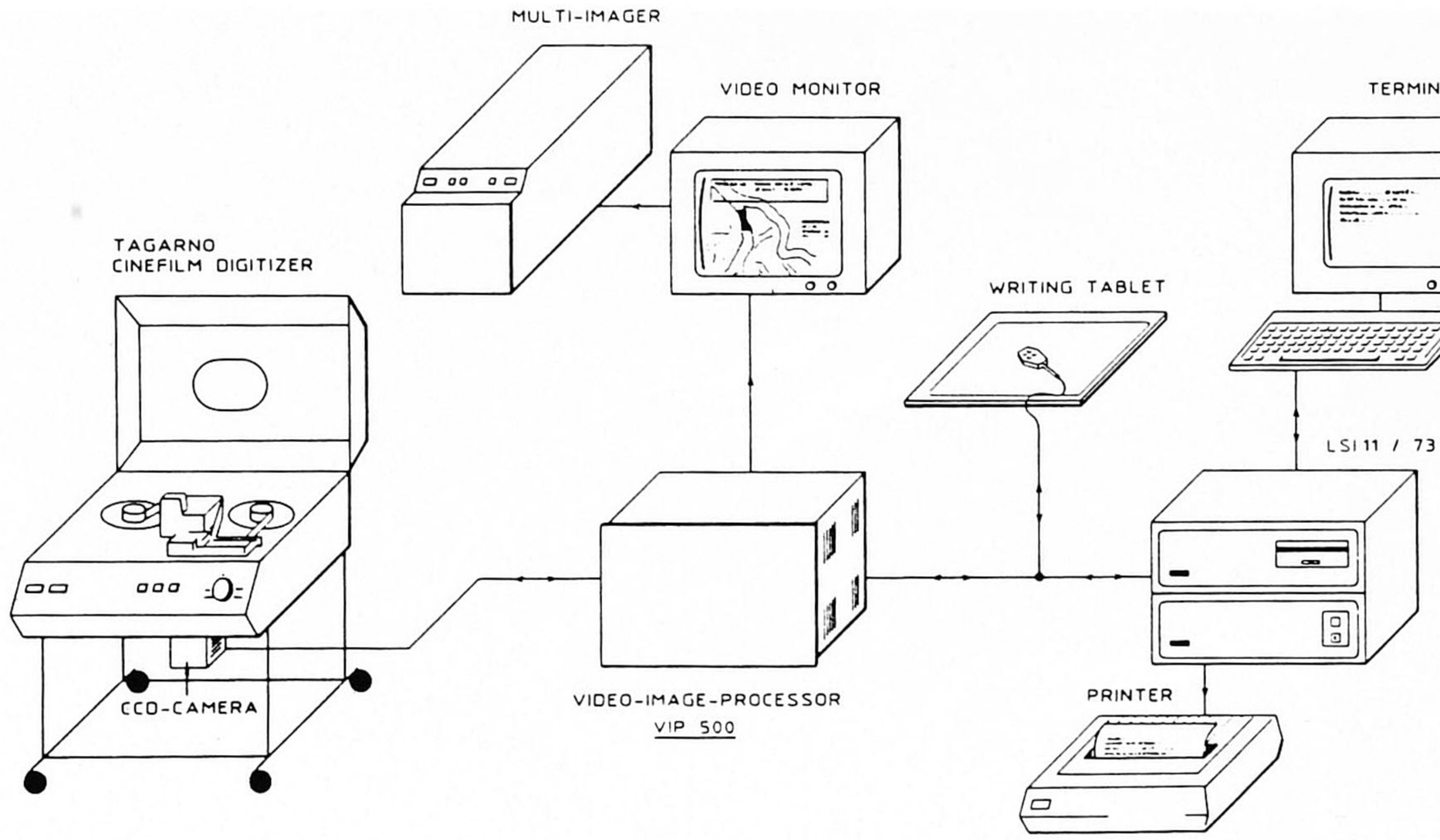

Fig. 1. Block diagram of the Pie Data Cardiovascular Angiography Analysis System (CAAS).

sitions; and 4) determination of the severity of a coronary obstruction in terms of absolute and relative parameters. These different steps will be described very briefly in the following paragraphs; details of these steps have been described elsewhere [12,13,16,17].

Calibration

Calibration of the diameter data of the vessels in absolute values (mm) is achieved by computer detection of the outer boundaries of a user-selected portion of the contrast catheter in the magnified mode. The contour data are corrected for the pincushion distortion in the image. From the corrected contour positions a mean diameter value is determined in pixels; the calibration factor is then expressed in mm/pixel with the known size of the catheter. We have studied previously which types of catheters are suitable for quantitative coronary angiographic studies [19].

Automated Arterial Contour Detection

The procedure for arterial contour detection requires the user to indicate a number of center positions in the magnified arterial segment (magnification factor 2×). Subsequently, the digital data are resampled along straight lines, called scanlines, perpendicular to the local directions of the smoothed centerline. Contours of the arterial segment along the scanlines are determined on the basis of the weighted sum of first- and second-difference functions applied to the resampled brightness information with so-called minimal cost criteria. If the user does not agree with part of the detected contours, these erroneous positions may be corrected interactively with the writing tablet.

This contour-detection procedure is then repeated with the centerline defined as the midline of the detected and possibly corrected contours. Finally, a smoothing procedure is applied to each of the detected contours, and the resulting positions are corrected for the pincushion distortion.

Contour Analysis

The diameter function D(i) of the arterial segment, calibrated in absolute millimeters, is determined by computing the distances between corresponding contour points to the left and right of the centerline. Figure 2 shows an example of the computer-processed midportion of an LAD-artery. The upper function in Figure 2 is the diameter function; the lower one, the densitometric area function, which defines for each point along the centerline the cross-sectional area of the vessel as assessed by densitometry. However, densitometric data will not be discussed in this paper. From the minimal value Dm of the diameter function at the site of the obstruction and the mean diameter value Dr at a reference position, the percentage diameter reduction is computed as:

$$\%\text{-D stenosis} = (1 - \mathrm{Dm/Dr}) \times 100\%.$$

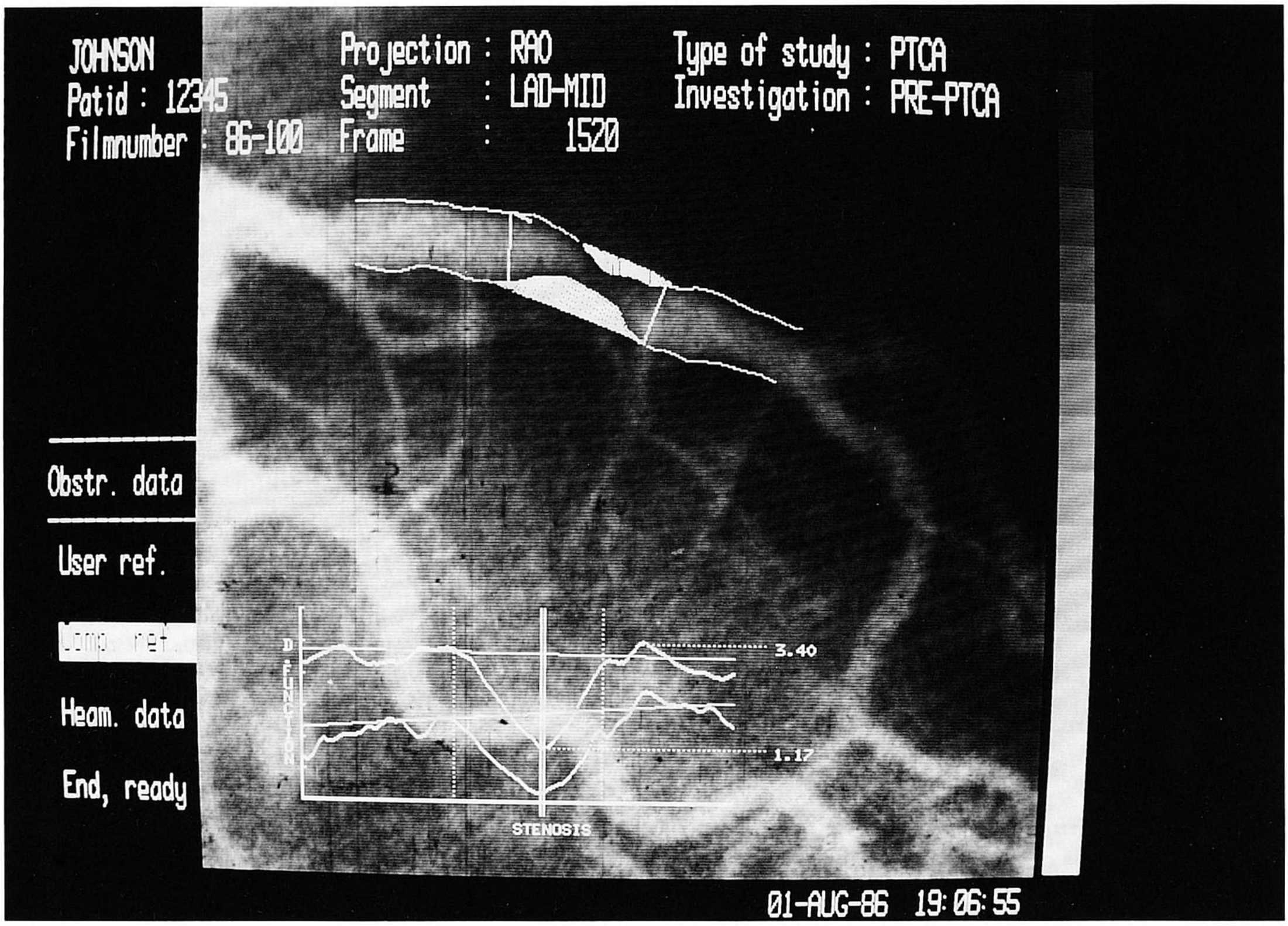

Fig. 2. Example of the quantitative analysis of a mid-LAD-segment with the CAAS. The contours were detected automatically; absolute and relative parameters were derived on the basis of the diameter function.

The extent of the obstruction is determined from the diameter function D(i) on the basis of curvature analysis and expressed in millimeters [16].

For the definition of the reference diameter value Dr, the computer-defined or interpolated technique was used. The basic principle of this technique is the computer estimation of the original width of the vessel over the obstructive region from the actual luminal diameter function.

On the basis of the proximal and distal diameter values, a new reference diameter function is reconstructed (straight line through the diameter function in Fig. 2), which represents an estimation of the size of the vessel before coronary disease had occurred. The reference diameter value Dr is now equal to the value of the reference diameter function at the site of the minimal-obstruction diameter.

ln addition, on the basis of the proximal and distal centerline segments and of the computed reference diameter function, the estimated original (reference) contours over the obstructive region can be reconstructed (Fig. 2). The difference in area between the reference and the detected luminal contours over the obstructive lesion is a measure for the "atherosclerotic plaque."

By these approaches the following quantitative data became available for the example of Figure 2:

Extent obstruction: 7.51 mm;
Reference diameter: 3.16 mm;
Obstruction diameter: 1.17 mm;
Reference area: 7.86 mm^2;
Obstruction area (densitometric): 0.84 mm^2;
Area plaque: 9.90 mm^2;
Diameter stenosis: 63%;
Area stenosis: 89%.

Patient Material

To study the possible dependency of the obstruction measurements on the selected image, 38 consecutive pa-

tient films were analyzed with the CAAS. Eleven of the 38 cinefilms were analyzed with the research CAAS; the remaining 27 films, with the Pie Data CAAS. In all cases the filmspeed was 25 frames/sec and the images were obtained with 7-inch image intensifiers. A modern, nonionic contrast agent (iopamidol) with low osmolality was used.

The selection of the frame judged optimal for quantitative analysis was performed by one senior cardiologist according to the following rule: Choose from the end-diastolic frame or a neighboring frame the optimal frame that shows that 1) the obstruction is free of overlap of sidebranches or other structures, 2) maximal sharpness of the vessel boundaries is observed, and 3) the obstruction is observed in its most severe appearance.

The selected frame was defined as frame 0. Because there may be slight differences in the selection of this optimal frame among different cardiologists, it is of interest to study the arterial dimensions assessed from a number of frames immediately before and after frame 0. For these purposes, we selected three frames preceding frame 0, identified as frames -1, -2, and -3, and three frames immediately following frame 0, denoted frames $+1$, $+2$, $+3$.

To be able to judge the variabilities that will be observed between these frames against the reproducibility of assessing a stenosis in exactly the same phase of the cardiac cycle, an eighth frame was selected exactly 1 cardiac cycle earlier or later than the optimally selected frame. Because of the differences in contrast filling of the coronary segment, in seven cases the frame was selected exactly 1 cycle prior to the selected frame (defined as -1c); in 25 cases it was selected exactly 1 cycle following frame 0 (defined as $+1$c); whereas in the remaining 6 cases, an appropriate frame exactly 1 cycle before or after the selected images could not be found; the types of coronary segments involved in these missing data were right coronary artery (RCA)-prox (1), RCA-mid (2), RCA-dist (1), circumflex coronary artery (Cx)-prox (1), and Cx-dist (1).

The calibration for this series of eight measurements per patient film was performed only once, because the geometry of the X-ray system with respect to the patient remained unchanged.

The 38 coronary segments analyzed were RCA-prox (4), RCA-mid (13), RCA-dist (2), left anterior descending artery (LAD)-prox (2), LAD-mid (10), Cx-prox (4), and Cx-dist (3).

Statistical Analysis

The variability in the measurements assessed from the frames other than frame 0 were defined by the standard deviations (S.D.) of the differences between these measurements and those from frame 0. Student's t-test for paired values was applied to determine the statistical significance between the measurements (border of significance, $P = 0.01$).

RESULTS

The parameters that were compared were the obstruction diameter (mm), interpolated reference diameter (mm), interpolated percent diameter stenosis (%), extent of the obstruction (mm), and area of atherosclerotic plaque (mm^2). The results are presented in Table I. The ranges of the mean differences and standard deviations

TABLE I. Mean Differences and Standard Deviations (Mean ± S.D.) of the Measurements in the Frames With the Measurements Obtained In Frame 0[a]

	Preceding optimal frame			Following optimal frame			Preceding or followed by ±1c[b]
Measurement	−3	−2	−1	+1	+2	+3	
Obstr. diam.[c] (mm)	−0.02 ± 0.24	0.02 ± 0.20	0.02 ± 0.22	0.006 ± 0.20	0.02 ± 0.19	0.009 ± 0.22	−0.05 ± 0.21
Ref. diam.[d] (mm)	0.03 ± 0.13	−0.007 ± 0.15	0.02 ± 0.09	0.02 ± 0.12	−0.03 ± 0.11	0.003 ± 0.13	−0.08 ± 0.18
%-D stenosis (%)	1.07 ± 7.27	−0.71 ± 5.98	−0.20 ± 6.46	−0.07 ± 6.45	−1.14 ± 6.29	−0.12 ± 6.79	0.11 ± 7.11
Extent (mm)	−0.12 ± 0.58	0.06 ± 0.54	0.05 ± 0.40	0.13 ± 0.47	0.14 ± 0.50	0.20 ± 0.50	−0.10 ± 0.45
Area plaque (mm^2)	0.21 ± 2.17	0.09 ± 1.76	0.32 ± 1.77	0.34 ± 1.94	0.13 ± 1.53	0.43 ± 2.30	−0.70 ± 1.75

[a]All differences were not significant, with the border of significance at $P = 0.01$.
[b]Cardiac cycle.
[c]Obstruction diameter.
[d]Reference diameter.

TABLE II. Ranges in the Mean Differences and Standard Deviation of the Measurements for the Seven Frames[a] With Respect to Frame 0, as Summarized From Table I

	Ranges	
Measurements	Mean difference	S.D. difference
Obstruction diam. (mm)	0.006–0.05	0.19–0.24
Reference diam. (mm)	0.003–0.08	0.09–0.18
%-D stenosis (%)	0.07–1.14	5.98–7.27
Extent (mm)	0.05–0.20	0.40–0.58
Area plaque (mm^2)	0.09–0.70	1.53–2.30

[a] −3, −2, −1, +1, +2, +3, and ±1c (cardiac cycle).

of the differences of the measurements in the various frames with respect to those in frame 0 have been summarized in Table II.

For all cases, the results of the different measurements were not found to be significantly different from the values at frame 0. For the obstruction diameter, the mean difference varied from 0.006 mm (= 6 μm) to 0.05 mm (= 50 μm), with the standard deviation varying from 0.19 mm to 0.24 mm. For the reference diameter, the mean difference values varied from 3 μm to 80 μm, with a standard deviation varying from 0.09 mm to 0.18 mm. Apparently, the reference diameter is more reproducible than the obstruction diameter, which is not surprising if the incomplete mixing of contrast agent is one of the major causes. For the mean differences in the percent diameter stenosis values, a lowest value of 0.07% and a highest value of 1.14% were found, whereas the standard deviations ranged from 5.98% to 7.27%, a very narrow range.

The mean differences in the extent (mm) of the obstruction varied from 50 μm to 200 μm, with the standard deviation between 0.40 mm and 0.58 mm. Finally, for the area of the atherosclerotic plaque, the range for the mean differences was found to be 0.09 mm^2 to 0.70 mm^2, with the standard deviations between 1.53 mm^2 and 2.30 mm^2.

From all these numbers no consistent pattern could be found to allow a particular frame to be characterized by its producing smaller values, in terms of mean difference or standard deviation, than any other frame. Also, the reproducibility of analyzing a coronary obstruction 1 complete cardiac cycle earlier or later than the originally selected cineframe seems to be just as good as taking a neighboring frame of frame 0.

These data demonstrate that the selection of an optimal cineframe for quantitative analysis does not seem to be as critical as one would suspect. Deciding on another frame, 1, 2, or 3 frames displaced from the "optimal" one, or even a complete cardiac cycle earlier or later, does not result in statistically significant differences, and the variability measures are all of the same order of magnitude.

DISCUSSION

The majority of the applications of quantitative coronary cineangiography require the comparison of the arterial dimensions in a control group with those in a treated group or the comparison of results pre- and post-intervention, possibly with the data from some later control angiograms, The sample size of the number of patients that need to be investigated to demonstrate a certain effect is proportional to the variability of the measurement technique divided by the number of years between angiograms squared [20]. From the viewpoint of the population size, duration, and cost effectiveness of a study, it is of great importance to minimize the variability of the angiographic data acquisition and computer-analysis procedures.

In previous studies we assessed the reproducibility of repeated analysis of the same cineframe ("repeated analysis") and of repeated cineangiography and computer analysis and came to the conclusion that standardization of the angiographic-acquisition procedure is very much important in obtaining the best variability measures [13]. A summary of these data is presented in Table III.

In these studies care was taken to select the images from repeated angiographic investigations at exactly the same moment in the cardiac cycle, preferably at end-diastole. In cases of obscured edges of the target artery segment by overlapping branches or other arteries or in cases of poor filling of the arterial segment (obstruction) with contrast agent, the frames were selected at another instant in time near end-diastole. Per patient film, the first and second cineframe were always selected in exactly the same phase of the cardiac cycle.

It must be clear that the ultimate selection of the cineframe to be analyzed is always done by a human, more-or-less experienced observer and that such subjective selection procedure is subject to inter- and intra-observer variations, despite the fact that a number of selection criteria may be defined as discussed under the previous heading "Patient Material." As a result, the question must be raised, What will be the effect on the reproducibility of the technique of selecting different cineframes in a coronary angiographic study?

When comparing the ranges of the standard deviations of the differences for the obstruction diameter, reference diameter, and %-D stenosis, as presented in Table II with the values from Table III, it becomes apparent that the results from the best-controlled repeated cineangiographic study lie within these ranges; the variability of the interpolated reference-diameter measurement with re-

TABLE III. Summary of the Differences (Mean and S.D.) in the Absolute-Diameter Measurements and Interpolated Percentage Diameter Stenosis for Repeated Analysis, and the Best-Controlled and Worst-Case Angiographic Studies [12,13]

	Mean difference			S.D. difference		
Diameter measurements	Repeated analysis	Best controlled	Worst case	Repeated analysis	Best controlled	Worst case
Obstr. diam. (mm)	0.00	0.00	0.00	0.10	0.22	0.36
Interp. ref. diam. (mm)	−0.10	0.05	−0.13	0.10	0.15	0.66
Interp. %-D sten. (%)	−2.08	1.21	−1.92	3.94	7.23	6.52

peated analysis of the cineframes (0.10 mm) also falls within the range of Table II. In addition, the variability in the %-D stenosis of the worst-case study falls within these ranges. This last observation is due to the fact that the quality of the angiographic investigation apparently has little influence on the variability of the relative interpolated %-D stenosis measurement. Thus, it may be concluded that the variabilities measured resulting from the different frame selections are comparable to those observed in the best-controlled angiographic studies; in general, are larger than the values observed from repeated analysis alone, as one would expect; and are smaller than those from the worst-case angiographic studies.

The problem now becomes to determine which factors are responsible for the measured variations in this study. First, all the possible variations in the data analysis procedure itself, as discussed in detail in references 12 and 13 are present. These variations include 1) quantum noise in the images, 2) noise contributions in the video or CCD camera, 3) quantitation errors in the analog-to-digital conversion, 4) the effects of resampling the data along scanlines through the square grid of the digital data, 5) observer variations in the definition of center positions within the selected arterial segment, 6) possible manual corrections to the detected contours, and 7) selection of beginning and end points of the obstructive lesion. According to Table III, these factors are responsible for variations in the obstruction diameter, reference diameter, and %-D stenosis of 0.10 mm, 0.10 mm, and 3.94%, respectively. Because the variabilities in this study in general are larger than these values, additional causes in the acquisition procedure must be present.

A factor that certainly plays an important role in the angiographic image-acquisition procedure is the variation in the quality of mixing of the contrast agent with blood. Other factors in the angiographic procedure mentioned in references 12 and 13 include differences in the angles and height levels of the X-ray gantry with respect to the patient at the time of repeated angiography, differences in the vasomotor tone of the coronary arteries, and deviations in the size of the catheter from the true size, as listed by the manufacturer. These differences do not apply in this particular comparative study, because for each patient study, different frames from the same angiographic investigation were analyzed. However, one additional factor must be taken into account, representing the variability in the size and shape of the coronary arterial segment from frame to frame; size changes may be caused by foreshortening of the vessel segment. In general, the variation resulting from this last factor will be small, since the images were selected in the end-diastolic phase, where there is little motion from frame to frame. However, it is certainly a factor that must be reckoned with.

Finally, it is known from the literature that the dimensions of a normal coronary arterial segment may vary by as much as $6.0 \pm 2.0\%$ over a cardiac cycle because of the pulsatile effect of the aortic pressure [21]. These variations were measured between end-diastole and end-systole. Therefore, the variations over several frames in the end-diastolic phase may be neglected, compared with other existing variations.

If we compare the error sources present in the repeated-analysis variability study and those in the present study, then we must conclude that the increase in the variabilities must be due to the following factors: quality of mixing of the contrast agent, the changes in size and shape of the arterial segment, and the pulsatile effect. It has been argued previously that the last two factors are probably very small, one reason why we must conclude that the quality of the mixing of the contrast agent with the blood plays a major role as a source of variation.

Spears et al. have also found that from among a great number of radiographic variables that may influence the quality of an angiographic image and the resulting quantitative measurements, the completeness of the filling of the arterial segment with the contrast agent has a statistically significant effect on the arterial measurements [14].

It may be concluded from our study that the selection of a cineframe for quantitative analysis in the end-diastolic phase of the cardiac cycle is not very critical. The variabilities in the measurements are not influenced in a statistically significant way if the selected frames in the

same cineangiographic film sequence are out of phase by a maximum of three frames at a film speed of 25 frames per second or if a frame is selected exactly 1 cardiac cycle earlier or later. Differences in the degree of filling of the arterial segment with the contrast agent probably are a major source of the variations, being potentially present in each of the selected frames. Other possible error sources in the data-acquisition procedure, such as changes in size and shape of the arterial segments and the pulsatile effect, probably play a minor role.

Therefore, the results from this study may be reassuring to those involved in quantitative coronary angiographic studies. They show that reliable quantitative data about coronary morphology can be obtained from cinefilm if certain, not extremely demanding, precautions are followed.

REFERENCES

1. Serruys PW, Booman F, Troost GJ, Reiber JHC, Gerbrands JJ, Brand M van den, Cherrier F, Hugenholtz PG.: Computerized quantitative coronary angiography applied to percutaneous transluminal coronary angioplasty: Advantages and limitations. In Kaltenbach M, Grüntzig A, Rentrop K, Bussmann WD (eds): "Transluminal Coronary Angiography and Intracoronary Thrombolysis. Coronary Heart Disease IV." Berlin: Springer-Verlag, 1982, pp 110–124.
2. Serruys PW, Reiber JHC, Wijns W, Brand M van den, Kooijman CJ, Katen HJ ten, Hugenholtz PG: Assessment of percutaneous transluminal coronary angioplasty by quantitative coronary angiography: Diameter versus densitometric area measurements. Am J Cardiol 54:482–488, 1984.
3. Serruys PW, Wijns W, Brand M van den, Ribeiro V, Fioretti P, Simoons ML, Kooijman CJ, Reiber JHC, Hugenholtz PG: Is transluminal coronary angioplasty mandatory after successful thrombolysis? Quantitative coronary angiographic study. Br Heart J 50:257–265, 1983.
4. Wijns W, Serruys PW, Brand M van den, Reiber JHC, Suryapranata H, Hugenholtz PG: Progression to complete coronary obstruction without myocardial infarction in patients who are candidates for percutaneous transluminal angioplasty: A 90-day angiographic follow-up. In Roskamm H (ed): "Prognosis of Coronary Heart Disease—Progression of Coronary Arteriosclerosis." Berlin: Springer-Verlag, 1983, pp 190–195.
5. Wijns W, Serruys PW, Reiber JHC, Feyter PJ de, Brand M van den, Simoons ML, Hugenholtz PG: Early detection of restenosis after successful percutaneous transluminal coronary angioplasty by exercise-redistribution thallium scintigraphy. Am J Cardiol 55:357–361, 1985.
6. Serruys PW, Geuskens R, Feyter P de, Brand M vd, Deckers J, Katen H ten, Reiber H: Incidence of restenosis 30 and 60 days after successful PTCA: A quantitative coronary angiographic study in 200 consecutive patients. Circulation 72 (Suppl III):140, 1985 (abstract).
7. Serruys PW, Hooghoudt TEH, Reiber JHC, Slager C, Brower RW, Hugenholtz PG: Influence of intracoronary nifedipine on left ventricular function, coronary vasomotility, and myocardial oxygen consumption. Br Heart J 49:427–441, 1983.
8. Serruys PW, Lablanche JM, Reiber JHC, Bertrand ME, Hugenholtz PG: Contribution of dynamic vascular wall thickening to luminal narrowing during coronary arterial vasomotion. Z Kardiol 72:116–123, 1983.
9. Deckers JW, Reiber JHC, Serruys PW: Long-lasting vasodilatory effect of intracoronary administration of Molsidomine metabolite SIN-1. In Bing RJ, Stauch M (eds) : "Ischemic Heart Disease and Heart Failure. Advances in Treatment with Molsidomine." Munich/Vienna/Baltimore: Urban and Schwarzenberg, 1986, pp 80–85.
10. Arntzenius AC, Kromhout D, Barth JD, Reiber JHC, Bruschke AVG, Buis B, Gent CM van, Kempen-Voogd N, Strikwerda S, Velde EA van der: Diet, lipoproteins, and the progression of coronary atherosclerosis. The Leiden intervention trial. N Engl J Med 312:805–811, 1985.
11. Holder DA, Johnson AL, Stolberg HO, Campbell M, Gunstensen J, Joyal M, Roberts R, Biagioni EM, Vaughan W, Romeo M: Inability of caliper measurement to enhance observer agreement in the interpretation of coronary cineangiograms. Can J Cardiol 1:24–29, 1985.
12. Reiber JHC, Serruys PW, Kooijman CJ, Wijns W, Slager CJ, Gerbrands JJ, Schuurbiers JCH, Boer A den, Hugenholtz PG: Assessment of short-, medium-, and long-term variations in arterial dimensions from computer assisted quantitation of coronary cineangiograms. Circulation 71:280–288, 1985.
13. Reiber JHC, Serruys PW, Kooijman CJ, Slager CJ, Schuurbiers JCH, Boer A den: Approaches towards standardization in acquisition and quantitation of arterial dimensions from cineangiograms. In Reiber JHC, Serruys PW (eds): "State of the Art in Quantitative Coronary Arteriography." Dordrecht: Martinus Nijhoff Publishers, 1986, pp 145–172.
14. Spears JR, Sandor T: Quantitation of coronary artery stenosis severity: Limitations of angiography and computerized information extraction. In Reiber JHC, Serruys PW (eds): "State of the Art in Quantitative Coronary Arteriography." Dordrecht: Martinus Nijhoff Publishers, 1986, pp 103–124.
15. Selzer RH, Shircore A, Lee PL, Hemphill L, Blankenhorn DH: A second look at quantitative coronary angiography: Some unexpected problems. In Reiber JHC, Serruys PW (eds): "State of the Art in Quantitative Coronary Arteriography." Dordrecht: Martinus Nijhoff Publishers, 1986, pp 125–143.
16. Reiber JHC, Serruys PW, Slager CJ: "Quantitative Coronary and Left Ventricular Cineangiography; Methodology and Clinical Applications." Dordrecht: Martinus Nijhoff Publishers, 1986.
17. Reiber JHC, Kooijman CJ, Slager CJ, Ree EJB van, Kalberg RJN, Tijdens FO, Plas JFAN van der, Frankenhuyzen J van, Claessen WCH: Taking a quantitative approach to cine angiogram analysis. Diagn Imaging 7:87–89, 1985.
18. Reiber JHC: Morphologic and densitometric analysis of coronary arteries. In Heintzen P (ed): "Progress in Cardiovascular Angiography." Dordrecht: Martinus Nijhoff Publishers, 1988 (in press).
19. Reiber JHC, Kooijman CJ, Boer A den, Serruys PW: Assessment of dimensions and image quality of coronary contrast catheters from cineangiograms. Cathet Cardiovasc Diagn 11:521–531, 1985.
20. Blankenhorn DH, Brooks SH: Angiographic trials of lipid-lowering therapy. Arteriosclerosis 1:242–249, 1981.
21. Hori M, Inoue M, Shimazu T, Mishima M, Kusuoka H, Abe H, Kodama K, Nanto S: Clinical assessment of coronary arterial elastic properties by the image processing of coronary arteriograms. Comp Cardiol:393–395, 1983.