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Detection and Quantitation of Coronary Artery Stenoses from Digital Subtraction Angiograms Compared with 35-Millimeter Film Cineangiograms

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To assess the ability to detect coronary artery narrowings from computer-acquired angiograms, a panel of 4 observers independently identified and measured focal coronary narrowings from digital subtraction angiograms and compared the results to those obtained from standard 35-mm cine film angiograms. Both cine and digital angiograms were obtained sequentially using selective intracoronary artery injection of standard amounts of iodinated contrast media. Digital images were obtained at 8 frames/s with a 512 × 512 × 8-bit pixel matrix. Modifications in the imaging chain for computer acquisition included a slower pulsed radiographic mode, a progressive scan camera, and initial storage of the images on an 80-megabyte digital hard disk. Postprocessing computer algorithms were used to enhance the unsubtracted digital images; these included single-frame, mask-mode subtraction, vessel boundary edge enhancement, and 4-fold pixel magnification. In 19 patient studies, 32 arteries were reduced more than 25% in diameter according to at least 1 of 4 observers on either the digital or cine film angiograms. There was no significant difference in the mean percent diameter narrowing for all the narrowings between the digital angiograms (53 ± 31%) and the cineangiograms (52 ± 31%). In addition, a 2-way analysis of variance yielded no significant difference between the amount of variability in the measurements between the cine film and the digital technique. This similar variability persisted when subsets of patients based on the degrees of stenosis were considered (e.g., only narrowings from 50 to 90% diameter reduction). Because digital acquisition permits immediate playback with image enhancement and greater ease of coronary artery quantification, digital angiography may have widespread clinical use for the detection and quantitation of coronary artery disease.

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The quality of computer-processed radiographic images has improved substantially over the past 5 years. Computer acquisition and enhancement of radiographic images is feasible for angiographic studies of large arteries such as the aortic, carotid, renal and femoral systems.[1–8] Right and left ventriculograms have been obtained that are comparable in overall quality to those obtained with standard film-based techniques.[9–13]

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Digital angiograms have some advantages over film-based techniques in that the studies can be performed less invasively or, if performed intraarterially, studies can be obtained with less contrast medium.[14,15]

Selective coronary angiograms recently have been obtained with computer processing.[16,17] A potential benefit of computer acquisition of coronary angiograms compared with cine film is that the images can be enhanced through the computer to improve contrast resolution. In addition, the computer images can be processed through the computer so that the severity of coronary artery disease can be measured readily. The present study compares digitally acquired and processed coronary angiograms with standard film-based cine coronary angiograms in the ability to detect, diagnose and quantitate focal coronary artery narrowings.

Methods

Cineangiograms: Coronary angiographic studies were obtained with a Siemens Cardioskop U-arm x-ray unit and a Gigantos-Optimatic generator. The nominal focal spot was 1.2 mm. Images were focused on a 7-inch cesium iodide image intensifier. Coronary artery catheterization was performed from the femoral artery and selective right and left coronary angiograms were obtained with a 7Fr or 8Fr Judkins catheter in multiple right and left oblique projections. All studies were performed with at least 2 cranially or caudally angulated projections. Standard film-based cine angiograms were obtained at 30 or 50 frames/s at 300 mA and 65 to 85 kVp. Images were recorded onVari-Cath film (Vari-X Corp.).

Digital angiograms: During the period of this study, computer technology evolved rapidly so that 2 different methods for acquiring digital subtraction coronary angiograms were evaluated. In the first method (phase I of the study), fluoroscopic images were digitized at 30 frames/s, subtracted in real time from a 16-frame blurred mask, and converted back into analog format for storage on ¾-inch videotape. The second image processing method (phase II) involved digitizing and storing unsubtracted pulsed radiographic images on a digital disk. In phase II, the subtraction process was performed after the study using a single-frame mask. The resulting subtracted images were further computer-enhanced before storage on ¾-inch videotape. Both digital methods were compared with standard film-based coronary angiograms. The angiograms obtained in phase I were reviewed to determine if the percent diameter narrowing measured by 2 observers was similar between the 2 techniques. The angiograms in phase II of the study were reviewed by 4 observers and analyzed to determine if the measurements were similar between the 2 techniques and if there was a greater percent variability in measurements obtained with 1 technique than the other.

Phase I—Blurred mask with direct analog storage of fluoroscopic images: Thirty-eight patients who were undergoing cardiac catheterization for clinical indications signed informed consent and agreed to participate in this phase of the study. The average age of the 38 patients was 54.1 years (range 40 to 74) and the average weight was 75.8 kg (range 49 to 109). There were 20 men and 18 women. Twenty-five patients had coronary artery disease and 13 had chest pain with normal cine film coronary angiograms.

Digital angiography technique: Each digital subtraction coronary angiogram was obtained immediately after a standard film-based coronary angiogram using the same patient placement, table and x-ray tube-image intensifier position. In this phase of the study, the x-ray system was operated in the continuous fluoroscopic mode with exposure levels set at 20 to 25 mA and 70 to 85 kVp, depending on the size of the patient. Five millimeters of aluminum filtration were used to decrease low-energy photons. To obtain digital images, the 30 frame/s video output of a Plumbicon TV camera (VideoMed III-C, Siemens Corp.) aimed at the x-ray image intensifier was connected to an image processing computer (Cardiac 1000, American Edwards Laboratories). Before injecting contrast material, an initial ½-second exposure (16 video frames) of the heart was digitized, summed and stored in the computer memory as a mask. The summation of 16 frames into a single mask had the effect of blurring cardiac motion, and hence is referred to as a blurred mask. Because the image processing computer did not have the capability of storing many images in a digital format, the incoming 1/30th-second fluoroscopic images were digitized into a 512 × 512 × 8-bit deep matrix, subtracted from the blurred mask in real time, and converted back into analog format for display on a television monitor in the catheterization laboratory and simultaneous storage on ¾-inch videotape. The videocassette recorder used for acquisition and playback was a Sony 5800 with a 2.6-MHz band width and a vertical resolution of 484 displayed lines. Fluoroscopic imaging was continued during and immediately after the intracoronary injection of 4 to 8 ml of Renografin 76®. No panning was performed during the digital coronary angiograms in order to diminish misregistration artifacts. An example of these analog stored images obtained in phase I are shown in Figure 1.

Analysis of analog stored images: The videotapes of the digital angiograms and the 35-mm film cineangiograms obtained in the same projection were reviewed independently by 2 observers. The cine film studies were projected onto a 15-inch Vanguard screen and the digital studies were replayed from the videotapes onto a 25-inch television monitor. The studies were analyzed for the presence or absence of coronary

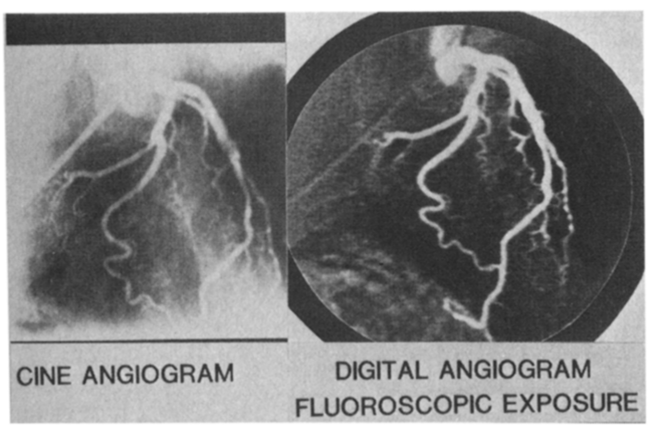

FIGURE 1. Comparison of a cineangiogram and a digital angiogram obtained with fluoroscopic exposure during phase I of this study. The digital angiogram used a 16-frame blurred mask to subtract out tissue densities overlying the heart. Both angiograms were obtained with 6 ml of contrast material injected directly into the coronary artery. The contrast resolution was improved on the digital angiogram, but the spatial resolution was superior on the cineangiogram.

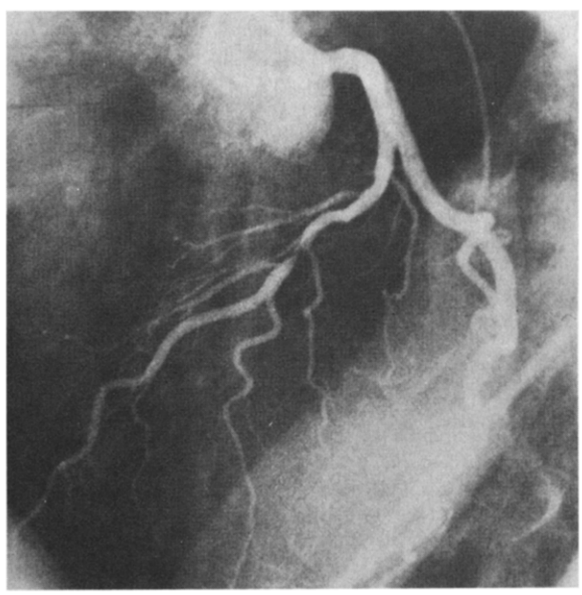

FIGURE 2. Standard film-based cineangiogram obtained during phase II of the study in the 60° left anterior oblique projection with 45° of cranial angulation. There is a significant lesion in the mid-left anterior descending coronary artery.

narrowing. A quantitative estimate of percent diameter narrowing was made by measuring the diameter of the vessel at the site of the narrowing with calipers. A segment of the coronary artery proximal to the narrowing that appeared normal angiographically was measured and the percent diameter narrowing was calculated.

The measurements of percent narrowing of all the stenoses from the cineangiograms were compared with the measurements of the stenoses from the digital angiograms in the same radiographic projections. If the measurements of the same lesion by the 2 techniques (cine film and digital acquisition) were within 10% of each other, the estimation of stenosis was arbitrarily considered to be equivalent. Because the cine film was considered to be the clinical standard, measurements greater than 10% difference between the 2 techniques were described as the digital study either overestimating or underestimating the narrowing compared with the cineangiogram.

Phase II—Single-frame mask with digital storage of pulsed radiographic images: A separate group of 19 patients who were undergoing cardiac catheterization for clinical indications signed informed consent and were studied in the second phase of the protocol. The average age of the patients was 64.4 years (range 24 to 72) and the average weight was 76.1 kg (range 63.6 to 113.6). There were 12 men and 7 women. Fifteen of the 19 patients had coronary artery disease and 4 had chest pain syndrome with normal coronary cineangiograms as determined by all 4 observers.

Digital angiographic technique: An image processing computer with digital storage capability was used in this phase of the study (Diasonics DA 100). This image processing computer had an 80-megabyte hard disk (Fujitsu Corp.) for storing images in a 512 × 512 × 8-bit deep digital format at 8 frames/s. However, because of technical limitations of the 80-megabyte hard disk, images could be played back for review at only 1 frame/s. The radiographic technique was selected by the operator at 4 to 8 mAs and 600 or 800 mA with 65 to 85 kVp, depending on the size of the patient, which resulted in exposures of 5 to 10 ms/frame. The only difference in the x-ray imaging system between this phase of the study and the first phase was the replacement of the previously used interlaced camera with a progressive scan camera (Model C-1800, Hamamatsu Corp.). The video output of the camera was transformed by the image processing computer in real time into a 512 × 512 × 8 bit matrix. All images were stored in an unsubtracted mode on the digital disk (Fig. 2 and 3). The unsubtracted images were also recorded simultaneously during acquisition on ¾-inch videotape to overcome the limited playback frame rate of the digital disk and to act as backup in case of disk failure. A 1- to 2-second series of x-ray exposures of the chest was taken just before injection of contrast material and continued for 6 seconds during injection. To reduce misregistration artifact, the patient was instructed not to breathe and panning of the image intensifier was not performed. After the injection was performed and the images recorded on the digital disk, post processing with mask mode subtraction was used to enhance the digital coronary angiogram (Fig. 4). In distinction from the first phase of the study where a summated 16-frame blurred mask was used, the mask chosen in the second phase of the study was only a single frame, which was selected from the thoracic images without contrast medium. This mask image was chosen so that misregistration was minimized.

In addition to mask-mode subtraction, an edge-enhancement algorithm and a magnification algorithm were used to enhance the digital images. The edge-enhancement algorithm was used to sharpen the boundary of the coronary arteries. During the edge enhancement process, the computer scanned across every pixel and noted where there was the greatest rate of change in gray levels. These gray-level differences were then amplified, with the result that arterial boundaries filled with iodine contrast became more pronounced (Fig. 5). In the magnification algorithm, a rectangular region representing one-fourth the overall area of the image was chosen by the operator. The computer then magnified this rectangular area 4-fold by displaying the 256 × 256 pixel area onto the entire monitor screen (Fig. 6).

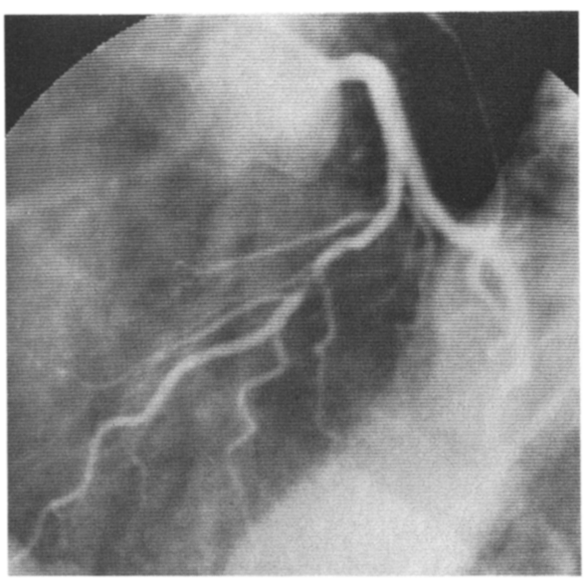

FIGURE 3. Digitally acquired and stored coronary angiogram obtained during phase II of the study using the same projection as in Figure 2. This computer image was photographed from the video monitor in an unsubtracted format and reveals the same lesion in the mid-left anterior descending coronary artery.

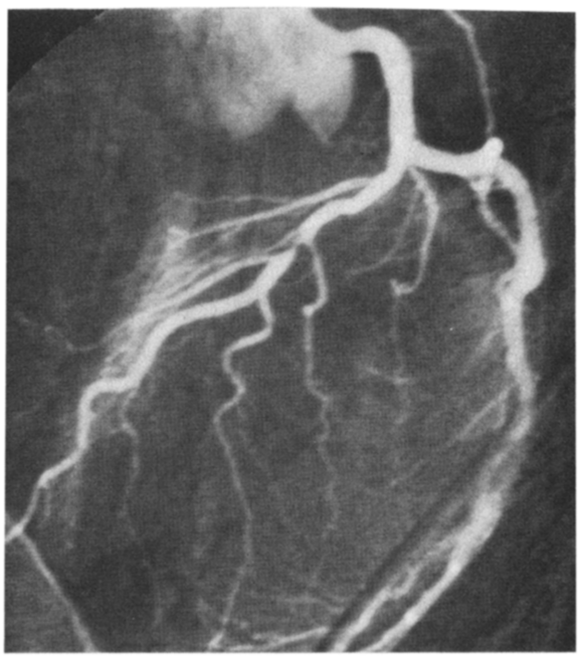

FIGURE 4. A single-frame mask-mode subtraction process was applied to the digital angiogram shown in Figure 3. Densities from bones and soft tissue have been subtracted from the coronary angiogram so that contrast resolution is significantly improved.

TABLE I Phase I Blurred Mask and Direct Analog Storage

38 pts studied
↓
3 pts with uninterpretable digital studies due to misregistration
↓
35 pts
↓

12 pts with normal cine
↓
Digital study also normal in all 12 patients

23 pts with 49 coronary stenoses visualized by cine
↓
Degree of narrowing (cine vs digital)

Equivalent:	37 obstructions (76%)
Cine greater narrowing:	9 obstructions (18%)
Digital greater narrowing:	3 obstructions (6%)

To facilitate review and evaluate a method for routine clinical use, each study was postprocessed from the digital disk and then down-loaded onto 3/4-inch videotape. Thus, each projection of the digital angiogram was recorded on videotape and consisted of unsubtracted images at 8 frames/s and subtracted images at 1 frame/s. In addition, selected magnified and edge-enhanced images that best showed the presence of coronary lesions were recorded on the tape. The digital angiograms were then reviewed from the 3/4-inch videotapes during playback on a 12-inch television monitor.

Analysis of digitally stored images: Four observers independently reviewed the cineangiograms and the digitally stored images that had been transferred to videotape. Measurements were made with calipers of the percent diameter reduction of any narrowing seen in either study that was thought by the reviewer to represent diameter narrowing of 25% or more. The narrowed segment was compared with a region of the artery immediately proximal to the segment that was considered to be free of angiographic evidence of disease. The cineangiograms were projected onto a 15-inch Vanguard screen for measurement of percent reduction of narrowing. The measurements of digital angiograms were made from a 12-inch monitor screen. All digital studies were reviewed before the cine angiograms were reviewed. This sequence was used to diminish bias of interpretation because the cineangiograms were considered to be the standard for diagnostic accuracy.

The interobserver variability for measuring the same lesions was determined by a 2-factor analysis of variance. The 4 observers' measurements of percent narrowing was calculated for 32 stenoses seen on the film-based cineangiograms, and these results were compared with the 4 observers' measure-

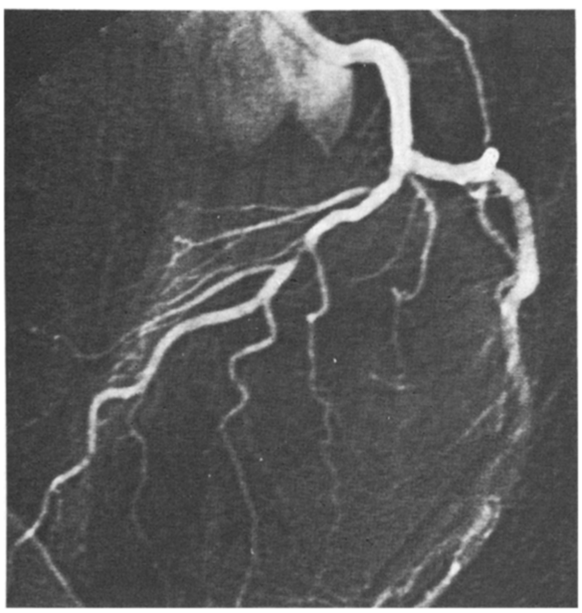

FIGURE 5. An edge-enhancement algorithm was applied to the single-frame mask-mode subtraction digital angiogram of Figure 4 to sharpen the boundaries of the coronary artery.

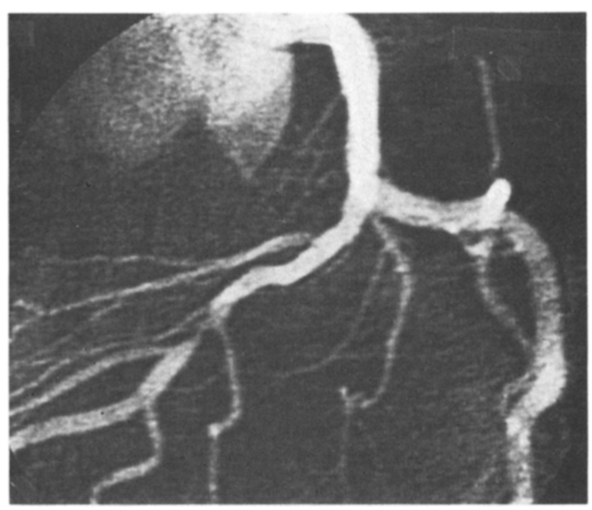

FIGURE 6. The 4-fold computer magnification of the edge-enhanced, single-mask mode subtracted digital angiogram shown in Figure 5. The region of interest to be magnified was chosen by the operator. In this case, the area of interest is the lesion in the mid-left anterior descending coronary artery.

TABLE II Phase II—Single-Frame Mask with Digital Storage: Analysis of Variance Summary Table

Source	Degrees of Freedom	Sum of Squares	F Test	Significance
Variance between cine and digital techniques:	1	0.01	0.07	NS
Variance among the 4 observers:	3	0.03	0.07	NS
Interaction between techniques and observers:	3	0.03	0.07	NS
Error within group:	280	34.50		
Total	287	34.56		

ments of the same narrowings from the digital angiograms. In addition, the mean percent narrowing for all 32 lesions as calculated by all 4 observers was determined for both the digital and cineangiograms. Statistical analysis of the mean percent narrowing was performed with a Student paired t test. A 2-tailed value of <0.05 was considered significant.

Results

Phase I—Blurred mask and direct analog storage: The results for phase I are represented in Table I. Three of the 38 patients included in phase I had uninterpretable digital subtraction angiograms as a result of misregistration artifact caused by breathing. Thirty-five patients had studies adequate for clinical evaluation. Both observers agreed that 12 of these 35 patients had normal cineangiograms, and in all 12 the digital angiogram was also interpreted as normal by both observers. In the 23 patients with evidence of atherosclerotic narrowing in at least 1 coronary artery, 49 arterial narrowings were seen on the cine coronary angiograms by both observers. The degree of measured percent diameter narrowing between the digital angiogram and cineangiogram were considered to be equivalent (within 10% of each other) in 37 lesions (76%). The cineangiograms revealed a tighter narrowing in 9 lesions (18%), whereas the digital angiogram was considered to demonstrate a tighter narrowing in 3 lesions (6%). The overall quality of the cine coronary angiograms was judged superior to the digital coronary images in this phase of the study. The spatial resolution for the 35-mm film was 4 line pairs/mm, compared with 1.5 line pairs/mm for the analog-stored digital angiograms.

Phase II—Single-frame mask and digital storage: There were 4 angiographic studies in which all 4 observers did not see a narrowing greater than 25% diameter stenosis in any coronary segment on both the digital and cine film studies. In the other 15 studies, there were 32 segments in which at least 1 observer saw a stenosis of more than 25% diameter narrowing on either the digital or cineangiogram. When the measurements from the 4 observers were averaged, there was no significant difference between the mean stenosis measured from digital (53.3 ± 30.7%) vs the cine film angiogram (52.0 ± 31.1%). All 4 observers agreed there were 5 coronary arteries with total occlusions seen on both cine film and digital angiograms. In addition, the range of individual estimates of specific narrowings between observers for the cine film angiograms varied between 0 and 60%. For the digital angiograms, individual estimates of specific narrowings between the 4 observers varied between 0 and 63%.

An analysis of variance was used to determine the interobserver variability. Since each of the 4 observers measured 36 coronary segments for both the cine film and the digital angiographic technique, a 2-factor analysis was used. The results of the analysis of variance are listed in Table II. In a matrix analysis of this size with 3 by 280 degrees of freedom, the F test would have to be >2.64 to reach statistical significance. There was no significant difference in the variability of measurements between observers for either the digital angiograms or the cineangiograms (Table II).

The 2-factor analysis of variance also assessed the variability of measurements between the cine film and digital techniques. The F test would have to be greater than 3.88 if there were a significant difference in variance between the 2 techniques. Analysis of variance did not demonstrate any statistically significant difference between the variability of measurements by the 2 techniques (Table II). In addition, the analysis of variance did not reveal any significant interaction between any individual observer and either of the 2 techniques. This lack of interaction in a 2-factor analysis of variance implies that there was no observer who decreased his variability of measurements when viewing either the film or digital studies.

There was also no significant difference between the 2 techniques for interobserver variability when the lesions were separated into various categories for the degree of narrowing. A separate analysis was performed for segments narrowed between 25 and 75%, 50 and 90% and 75 and 100%. None of these separate groups of varying degrees of narrowing altered the variability in interobserver measurements between the 2 techniques.

The overall quality of the digital coronary images obtained in this phase of the study was judged to be at least as good as that of the film-based images. Although spatial resolution was less in the digitally stored images, contrast visibility was significantly improved.

Discussion

Over the time course of this study, computer technology evolved rapidly so that 2 distinct methods for acquiring and storing digital images could be evaluated. In phase I of this study, a prototype digital image processing computer was used that digitized the fluoroscopic images at 30 frames/s. The incoming images containing contrast were subtracted in real time from a ½-second (16-frame) blurred mask of the thorax obtained before the injection of contrast. A blurred mask was used to reduce potential motion artifact created by the beating heart. Because of the limitation of computer storage, the subtracted images were immediately transformed back into an analog format for storage on videotape. These digital angiograms could be reviewed from the videotape at 30 frames/s and a quantitative analysis of these images revealed that they were concordant (i.e., within 10% of the film-based cineangiograms) for 76% of the lesions. The 2 observers who reviewed the phase I digital images measured 6% of the coronary lesions as being more narrowed on the digital images compared to the film-based angiograms, while 18% of the segments were measured as less narrowed on the digital images compared to the studies on film. The spatial resolution of the phase I digital images was significantly lower than that of the film-based angiograms. In addition, there was a considerable amount of noise in the videotape images. Although phase I of the study was useful in demonstrating the feasibility of obtaining selective coronary angiograms with digital processing, it was clear that the overall image quality needed to be improved.

In phase II of this study, another prototype computer system was used that differed significantly in several design aspects from the first image-processing computer. The major difference was that the second computer was capable of storing the 512 × 512 × 8 bit digital images on an 80-megabyte hard disk. The acquisition rate was more limited with this computer because of the large amount of digital information contained in each image (262,144 bytes/image). The method used in phase II also differed from phase I in that images were acquired with a higher-energy pulsed radiographic mode. In addition, the radiographic images were transformed into a video signal with a progressive scan camera instead of a Plumbicon interlaced camera. Because slower frame rates were used in phase II, the camera image residual left on the input phosphor could be scrubbed 4 times between exposures which decreased video noise in the system.

A fifth difference in the 2 phases of the study was that a single image was used as the mask in phase II instead of the 16-frame summated blurred mask used in phase I. However, despite the presence of cardiac motion, the single-frame mask-subtraction images were of good quality without significant artifact caused by cardiac motion. In addition, the computer contained software algorithms which could be used to move the mask relative to the contrast-filled images to correct for misregistration due to breathing. In 2 patients, misregistration due to breathing created significant artifacts in the images but did not prevent quantitative analysis. In these instances, the unsubtracted digital images were still clinically useful and were used to detect and quantitate lesions.

The comparison of the phase II digital images and film-based cineangiograms was assessed by performing an analysis of variance. It is well known that there is significant interobserver discrepancy whenever a panel of trained angiographers attempts to interpret the extent of narrowing on coronary angiograms.[18–22] Because the actual arterial dimensions cannot be measured except with phantom studies, there is no absolute value of diameter reduction with which the observers' measurements can be compared. An analysis of variance will determine if the amount of variability between observers for interpreting the cineangiograms is different from their variability in interpretation of the digital angiograms. In the present study, no significant difference in variability was found between the measurements for percent narrowing between the 2 techniques. Also, there was no significant difference in the mean percent narrowing for all the lesions between the digital angiograms (53.3 ± 30.7%) and the cineangiograms (52.0 ± 31.1%). The magnitude of the difference between measurements of the 4 observers for specific segments varied between 0 and 63% for the cineangiograms which was not significantly different than the range of measurements from the digital angiograms (0 to 60%). This variability was due in large part to the observers incorrectly identifying the arterial segment in which a stenosis was seen. When studies were subsequently reviewed, there were no instances in which the spread between observer measurements would be as great as 60% in the same segment.

A comparison between the digital images and standard film-based angiograms involves several areas of subjective analysis that are difficult to quantitate. The digital images obtained for this study were acquired at 8 frames/s. The playback rate for image review varied between 1 and 8 frames/s depending on whether the images were unsubtracted or post processed with single mask mode subtraction. Although 105-mm spot films have been used at these slow framing rates, most cardiologists are familiar with the more rapid framing rates of cine film at 30 to 50 frames/s. High framing rates are necessary when nonangulated views are used because vessels are superimposed and segments are partially hidden for a portion of the cardiac cycle as in the standard right anterior oblique view. Despite the lower frame rates used during playback of the digital images in this study, no significant obstructions were missed on the digital images obtained in phase II by the panel of observers. This is most likely because of the cranially and caudally angulated projections that were used in obtaining the angiograms. These projections tend to decrease foreshortening and overlapping of the proximal vessels of the left coronary artery branches.[23–25] However, these angulated views have deficiencies. One problem created by the angulated projections is that the left anterior oblique cranial view superimposes portions of the left coronary artery over the spine or diaphragm. This variability in tissue density creates very dark or light areas of x-ray penetration, which decreases visibility on film-based techniques. Digital processing of images can diminish this problem by subtracting out the spine and diaphragm which in turn significantly improves the contrast resolution on digital angiograms compared with cine film. This contrast enhancement is also useful for improving the visibility of low contrast vessels such as coronary collaterals. In addition, the computer format permits the alteration of contrast and brightness values to bring out information from the dark or light areas of the image in contradistinction to film where the contrast is fixed during the development process.

Another benefit of digital acquisition of coronary angiograms is that the digitally subtracted and enhanced images are available for immediate review in the catheterization laboratory. The digitization process occurs in real time and the postprocessing for image enhancement requires less than 2 minutes. This aspect of digital imaging is useful when immediate clinical decisions are dependent upon the results of the angiogram. One example of this occurs during coronary angioplasty where we have found the immediate feedback from the digital images to be very useful. Perhaps the most important potential benefit of digital coronary angiography is that postprocessing algorithms can be developed for quantitating coronary artery narrowing, such as the edge-detection method of Brown et al[26,27] or nongeometric methods such as videodensitometry.[28,29]

Although digital processing of coronary angiograms has several advantages, there are some disadvantages of performing coronary angiography with the digital technique. The most significant problem is misregistration artifact, which is caused by motion in the image between the time that the mask is taken and subsequent images with contrast material are obtained. To diminish misregistration, panning of the image intensifer during the injection of contrast material was not performed in our studies. In this study, a 7-inch image intensifier was used and the full circular field was used so that panning was not necessary to visualize the entire coronary artery system. We also found that there was an advantage to storing the initial images in an unsubtracted format on a digital disk. In the 2 patients who had significant registration problems caused by motion of the diaphragm, the unsubtracted digital images could still be used to diagnose and quantitate the amount of coronary disease.

Another problem with the current digital imaging system is oversaturation of the television camera. Oversaturation occurs when low-density lung tissue is in close proximity to higher-density tissue. The high flux of photons required to penetrate the denser tissues saturates the area over the less dense tissues on the input phosphor of the television camera. This problem can be minimized by placing some beam attenuation material at the portions of the field where the heart and lung are contiguous, such as the anterior border of the heart in the right anterior oblique projection. Oversaturation may be solved by using solid-state cameras such as those that use charge-coupled devices as the photon-sensitive detector.

One of the technical difficulties with the computer system used in phase II of the study was that disk space for image storage was limited. The 80-megabyte hard disk held approximately 250 images of a 512 × 512 matrix. In addition, the transfer rate of data during playback from the disk for permanent storage on videotape was relatively slow, 1 frame/s. After this study was performed, a high-speed parallel transfer disk with 475-megabyte storage capacity was added to the computer system (Data Q, Vas-Matrix Corp.). This new digital disk can store up to 800 images and can acquire and play back a 512 × 512 matrix at 30 frames/s.

One of the important practical problems with digital image processing is the exchange of coronary angiographic images. Although digital image data is theoretically transmittable by wire or satellite between hospitals without degradation in the image, this capability is not presently available. As an immediate practical solution, we transferred the digital images after postprocessing enhancement onto a standard 10-minute, ¾-inch videotape cassette. This 10-minute tape included the unsubtracted coronary angiograms at 8 frames/s as well as the subtracted images at 1 frame/s. Selected spot views of the areas of coronary stenosis were subtracted, edge-enhanced and digitally magnified 4-fold. Furthermore, each videotape included 12-ml digital left ventriculograms at rest and during atrial pacing, along with a printout of the computer analysis of the ventricular wall motion. This videocassette is used at our catheterization and surgical conferences and can be sent to other hospitals for review on standard ¾-inch videotape recorders.

In conclusion, digital image processing during selective coronary angiography is feasible and produces coronary images that are comparable in overall quality and clinical usefulness to film-based angiograms. In addition, digitally acquired angiograms compare favorably in terms of interobserver variability with cineangiography with respect to stenosis identification and quantitation of diameter narrowing due to atherosclerosis. Because the digital format permits immediate review of coronary images and allows simplified quantitative analysis, these digital coronary angiograms should be clinically useful as a method for obtaining routine coronary angiograms. As a result of our experience with digital coronary angiograms, we converted our cardiac catheterization laboratory from one that used film as the primary storage medium to one in which all angiograms, both ventricular and coronary, are digitally acquired, processed and stored on ¾-inch videotape. Experience with this method during routine clinical use has been encouraging.

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