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Training Physicians and Health Care Providers to Accurately Read Coronary Arteriograms

A Training Program

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ABSTRACT

Patterns in visual interpretation of coronary arteriograms (CAs) frequently cause incorrect assessment of percent diameter stenosis (%DS). These errors result in overestimating the results of angioplasty as well as of the number of arteries significantly affected by coronary artery (CAD) disease.

Methods. Forty-one physicians, nurses, and students participated in the standardization of 45 Kodachromes (39 arteries, 6 phantoms) and 5 photographic reproductions. Eleven of the 41 participated in a three-part training program designed to eliminate errors and improve accuracy of interpreting %DS from CAs.

Results. Improvement in reading %DS was seen in 69% of CAs with statistical ($P \leq 0.05$) improvement in one third of these cases, whose narrowings ranged from 4% to 84 %DS. Variability of reporting was reduced in 26% of the cases. Skewing, representing an overestimation of "severe" disease and underestimation of "less severe" disease, was reduced with statistical improvement ($P \leq 0.05$) in reported %DS noted after training. Similar improvement was seen with phantoms but not in photographic images where the arterial edges were outlined.

(continued on next page)

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(Abstract continued)
Conclusion. The outcomes of clinical management, invasive and interventional (mechanical, thrombolytic) procedures, as well as research studies depend in part upon the accuracy of reading %DS from CAs. Most studies to date have been completed using extremely unreliable estimates of %DS with resultant problems in data interpretation. The use of this standardized training program has led to significant improvement in accurately assessing CAD.

CONDENSED ABSTRACT

Visual interpretation of percent diameter stenosis (%DS) from coronary arteriograms results in underestimating stenosis severity for "mild" disease and overestimating "severe" disease. These patterns in reading stenosis severity yield misinterpretation of angioplasty results as well as of the number of vessels significantly diseased. Forty-one physicians, nurses, and students participated in a training program designed to reduce errors made while reading %DS from coronary arteriograms. Following the three-part training program, participants demonstrated improvement in 69% of the arteries, with statistical ($P < 0.05$) improvement in one third of these. The improved interpretation resulted in more accurate assessment of the severity of coronary artery disease present, both before and after interventions. Utilization of this training program in cardiology fellowship programs would result in better interpretation of disease severity by cardiologists.

Introduction

Although cardiac catheterization has been used as a method for determining coronary artery disease (CAD) since 1959, no training program has yet been developed to instruct physicians and health care providers on how to accurately read percent diameter stenosis (%DS) from coronary arteriograms (CAs). In 1975 the first report looking at interobserver and intraobserver variability was published.[1] It demonstrated that the greatest inconsistencies were in the interpretation of stenosis severity for left anterior descending (LAD) and circumflex (LCx) arteries. No differences were noted between interpretations made by cardiologists and noncardiologists. Later, interobserver variability in reading %DS from CAs resulted in disagreement about stenosis severity in 35% of the reported cases.[2] Similar discrepancies were noted when an 18% standard deviation for interpretation of %DS was noted in 1977.[3] This same study revealed disagreement in stenosis severity in 31% of the cases.

Thirteen years later, researchers demonstrated that level of experience had no effect on the accuracy of reading CAs.[4] This study, like previous work,[1] demonstrated that the reading of CAs did not improve despite training in cardiology fellowship programs. In 1991, visual interpretation of %DS was shown to follow patterns that resulted in errors when compared with results obtained by use of quantitative coronary arteriography (QCA).[5] As a result of these errors, "severe" disease (> 50 %DS) was overestimated and "mild" disease (≤ 50 %DS) underestimated, resulting in an overestimation ($P \leq 0.001$) of perceived benefit from angioplasty. This undoubtedly accounts for some of the restenosis reported clinically. Additionally, visual determination of the presence or absence of three-vessel CAD resulted in almost twice as many coronary artery bypass grafting (CABG) operations as compared with results obtained with QCA. Despite these significant problems, clinicians and researchers have continued to use visual estimates of CAD without the benefit of a training program designed to improve the reading of %DS from CAs.

With the use of QCA to better define the parameters of atherosclerosis[6,7] and their impact upon stenosis flow reserve (SFR), 1040 independent arterial stenoses were analyzed. This information, along with phantom studies, was used to better understand the way in which observers read %DS. When the results of visually reported %DS[5-7] were compared with QCA-determined percent area stenosis (%AS), a significant correlation ($r = 0.991$) was discovered. Since individual observers could not be reporting %AS based upon two-dimensional CAs, other variables were studied and compared with %AS. The results of %AS and density data were sufficiently similar[6] to suggest that CAs are being interpreted on the basis of density or brightness but are reported as %DS.

This study was designed to answer the following three questions: (1) Can physicians and other health care providers be trained to more accurately read %DS from CAs by using this training program? (2) Can the use of this training program have an important clinical impact by eliminating the overestimation of "severe" disease and underestimation of "less severe" disease, resulting in more accurate assessment of CAD, improved interpretation of interventional procedures, and the elimination of unnecessary CABG operations? (3) Are there any significant differences between the interpretations of %DS made from CAs by physicians, nurses, and students or between men and women?

Methods

Study Population

Forty-one physicians (cardiologists, internists, family practitioners, and anesthesiologists), nurses (RNs, BSNs, and MSNs) and students (graduate, residents, and cardiology fellows) were involved in the standardization of Kodachrome and photographic images of coronary arteries and/or phantoms. Eleven participants (5 physicians, 3 nurses, and 3 students) were enrolled in a three-part training program designed to instruct them on how to avoid misinterpretation of %DS while improving their accuracy in interpreting stenosis severity. Only 2 of the 11 individuals had prior experience in reading CAs. Readers ranged from approximately age twenty to sixty-five, with up to thirty-five years of clinical experience. There were 32 men and 9 women in the standardization segment, and 6 men and 5 women in the final training program.

Training Session One

During this session readers were asked to report %DS for each of 45 Kodachromes representing 39 arteriograms and 6 phantoms. Each arteriogram represented a stenotic lesion[5] at end diastole. Each stenosis was marked with an arrow identifying the site in question to ensure that all subjects were reporting the same region. Subjects then reported the perceived %DS present for each given artery. Five additional photographic reprints (Figure 1) with stenosis and vessel edge identification were then analyzed. Readers were then asked to report %DS for each of the photographic images. Each of the arteries and phantoms were presented randomly to exclude any relationship to artery site or stenosis severity.

Readers were allotted sixty seconds for interpretation of each stenosis. Additional time was available, but no reader required more than sixty seconds per stenosis. Each of the arteriograms and phantoms presented was reproduced from previously standardized and reported[5] CAs. Each Kodachrome was converted from a tagged image file format (TIFF) image with 1-to-1 magnification and 641-by-480 pixels. Each of the 5 photographic reproductions was 10 × 14 cm, with vessel edges traced as well as identification of normal regions before and after the respective stenoses.

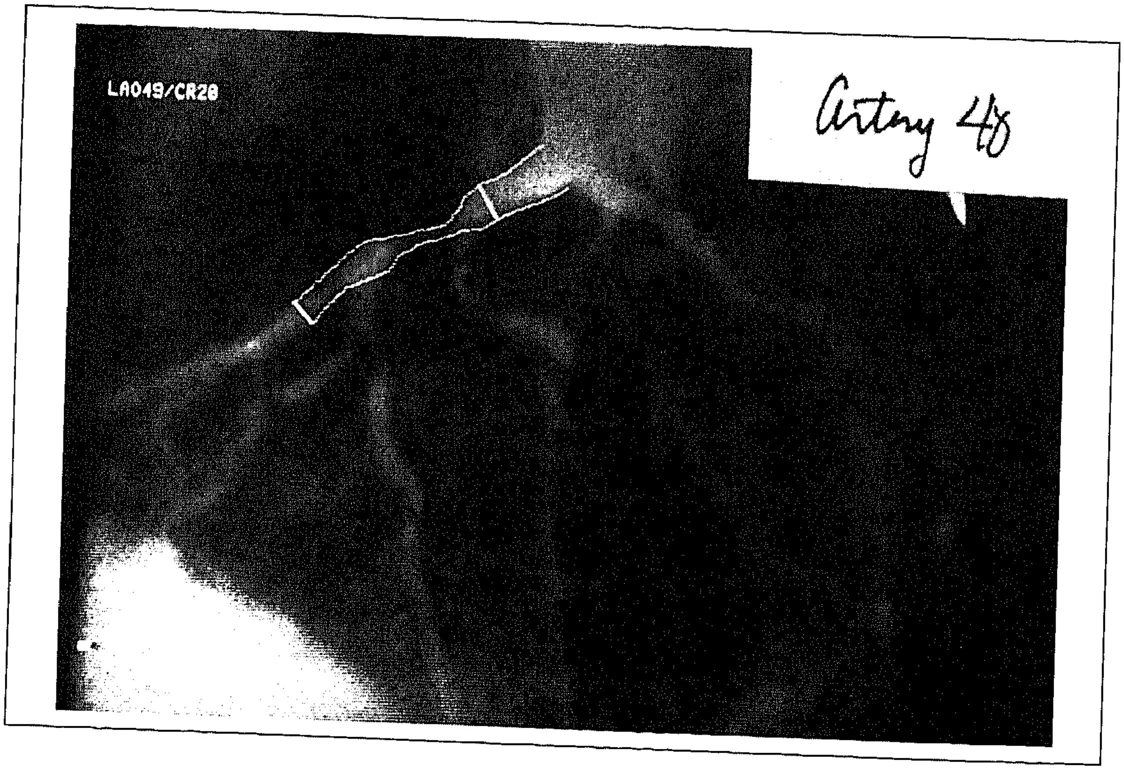
Selection of Coronary Arteriograms

From 212 stenotic lesions and 8 phantoms previously reported,[5] 44 stenotic coronary arteries and 6 phantoms were selected for use in this training program. Images were considered appropriate if end-diastolic projections clearly demonstrated the stenotic region in question after being reviewed by three independent observers. Diameter stenosis of the Kodachrome arteries ranged from 4% to 84%, with no two narrowings having the same stenosis severity. These 39 arteries represented 13 right coronary arteries (RCAs), 13 LADs, and 13 LCx arteries. Stenotic narrowings came from proximal, mid, and distal regions of all three coronary arteries. The five photographically reproduced arteries ranged from 11% to 63 %DS, while the 6 phantoms ranged from 0% to 83%.

Training Session Two

At the end of the first training session, participants were given seven papers[1-7] to read before

Figure 1. Example of photographic reproduction of stenotic coronary artery. This is an example of an LAD artery taken from the left anterior oblique (LAO) orientation. In this example the edges of the stenotic region are demarcated with the proximal and distal regions noted by lines drawn perpendicular to the vessel walls.



attending the second session, one week later. During the second one-hour session, each of the seven papers was reviewed with the following major points being made. In 1975 inconsistencies in interobserver and intraobserver variability was first reported when the results of %DS for LAD and LCx arteries were interpreted by 22 cardiologists and surgeons.[1] This demonstrated not only that inconsistencies occurred but also that despite the presence of "training programs," no difference in interpretation of lesions existed between these two groups of physicians. The following year 2 radiologists and 2 cardiologists interpreted stenosis severity, yielding disagreement in 35% of the cases.[2] This disagreement did not follow a pattern, suggesting that there were no significant differences in the training of these 4 individuals. This was confirmed the following year when panel reading confirmed disagreement in 31% of the cases, regarding whether a particular stenoses was "severe" or not.[3] Additionally, the standard deviation was 18% for any given stenosis. In 1990, it was determined that the errors in reading %DS were not related to any particular region of the country or to the level of experience/training.[4] As before, standard deviations in interpreting %DS were equivalent (15%) to that previously reported.

Given the information from earlier studies,[1-4] the emphasis then turned to understanding why the errors are made and how they can be corrected. Work completed between 1990 and 1994 demonstrated that visual reporting of %DS actually represented %AS.[5-7] Furthermore, results of %AS matched density data. This interpretation of density/%AS, with reporting as %DS, has resulted in the overestimation of "severe" ($\geq$ 50 %DS) disease,[5] the underestimation of "mild" disease (< 50 %DS), and the subsequent overestimation of percutaneous transluminal coronary angioplasty (PTCA) results in the clinical setting,[5] accounting in part for the restenosis seen in one third of PTCA cases. Additionally, the visual interpretation of %DS results in the statistical overestimation of triple-vessel disease, resulting in increased referrals for CABG operations.[5] Given this understanding of the way in which CAs are being misinterpreted, as well as the resulting significant clinical problems that can result from these errors, the training session then focused on practical examples of reading CAs and on edge detection of coronary arteries, while avoiding the problem of interpreting density/%AS.

Multiple slides of coronary artery stenoses and phantoms were presented to subjects for interpretation. Each arteriogram was then traced, the edges of the vessel in question being demonstrated and the brightness/darkness/density of the artery in question being ignored. Subjects then learned to analyze the vessel before and after the stenosis to determine the normal region of the artery. A comparison was then made for determination of %DS. Not only have these particular arteries and phantoms been standardized, but also the visual and QCA-reported %DSs of these images have been accepted as correct in previous publications.[5-7] As such they have become the accepted standard.

A two-week period was used for trainees to review the manuscripts and notes provided during the training session. This also provided time to work on the training booklet, providing practice in accurately determining %DS from photographs, prior to their return for session three.

Training Session Three

Each of the 50 stenotic arteries and phantoms presented in session one were reexamined for %DS by use of the same procedure outlined for training session one. The order of presentation of each of the Kodachromes was different from that used during the first session. During this session, subjects employed reading techniques developed during the second session, as well as from the workbook.

Statistical Analysis

Descriptive statistics consisting of mean ± standard deviation, variance, and skewness were determined for each stenosis before and after training. Results were compared among physicians, nurses, and students, as well as between men and women. Unmatched two-tailed t tests were used to determine differences between groups of participants as well as changes before and after training. Changes in variability were determined before and after training by F-ratio analysis.

Results

Of the 41 individuals involved in this study, 11 participated in interpretation of stenosis severity both before and after the clinical training designed to improve assessment of %DS. The remaining individuals were used to standardize the pretraining interpretation of stenosis severity. In the 41 participants, there were no statistical differences among physicians, nurses, or students (P = NS) before training. Additionally, there were no differences (P = NS) between interpretations made by men and women. In the 11 individuals participating in the training program, there were no statistical differences (P = NS) between groups of individuals either before or after training.

Improvement in reporting %DS was seen in 27 of the 39 (69%) Kodachrome reproductions of arteries after training, with statistically significant improvement in 33% of the cases. The results for these 9 arteries are shown in Table I and Figure 2 and represent disease ranging from 10% to 82 %DS. As shown in Table II, the variability in reporting %DS after training was reduced in 10 of these 39 (26%) arteries.

An example of %DS interpretation of these 39 arterial stenoses by a trainee with no prior experience in reading CAs, is shown in Figure 3. The pretraining results were comparable to those with individuals having previous experience reading CAs. The posttraining results demonstrated improvement consistent with that seen for all participants in the training program. Figure 3 demonstrates less overestimation of stenosed coronary arteries that have >50 %DS and less underestimation of arteries with ≤ 50 %DS after training.

When cumulative results for all trainees were compared before and after training by 50% and 25% increments, the results were better following training. With further analysis of the data into 10% increments, the results after training were statistically better for 0–10 %DS ($P \leq 0.01$) and 81–90 %DS ($P \leq 0.05$). There was less variability after training for 31–40 %DS ($P \leq 0.05$), 41–50 %DS ($P \leq 0.05$), and 71–80 %DS ($P \leq 0.001$). Correction of over-

Table I

Statistical Improvement Is Seen in 33% of the Arteries Where Training Improves Reading of Percent Diameter (%DS) Stenosis

Actual Percent Diameter Stenosis	Before Training %DS	After Training %DS	Statistical Significance (P)*
10	1.39	6.00	0.05
19	36.22	21.00	0.025
35	57.28	49.91	0.05
54	66.94	56.00	0.01
63	86.78	76.64	0.05
74	86.33	70.91	0.025
76	49.67	61.18	0.05
77	89.61	77.36	0.025
82	98.50	78.46	0.05

* P≤ 0.05 or greater is statistically significant.

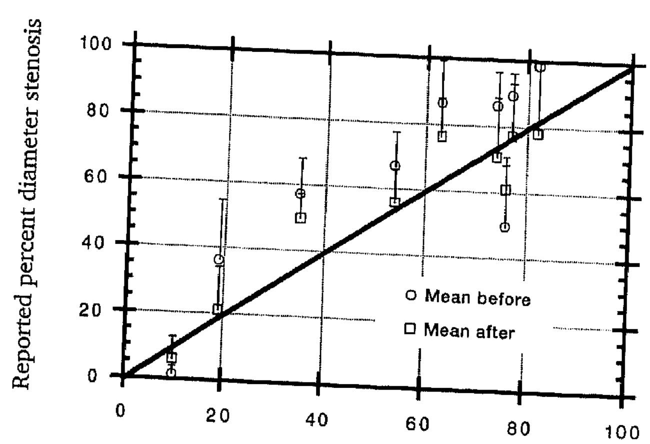


Figure 2. Actual percent diameter stenosis vs reported percent diameter stenosis before and after clinical training. The results of reported percent diameter stenosis (y-axis) before training (open circles) and after training (open squares) with their respective standard deviations are plotted against actual percent diameter stenosis as displayed on the x-axis. Improvement in reporting percent diameter stenosis after training is noted for disease ranging from 10% to 82%.

Table II

Reduction in Variability of Reported Percent Diameter Stenosis (%DS) Seen After Training

Actual Percent Diameter Stenosis	Before Training %DS	After Training %DS	Statistical Significance (P)*
Arteries			
29	19.21	11.53	0.05
38	20.43	9.58	0.01
47	16.12	7.10	0.01
53	14.29	8.45	0.05
55	28.12	13.62	0.05
58	18.92	9.51	0.05
60	17.68	10.41	0.05
65	21.59	12.22	0.05
76	21.24	7.53	0.01
84	22.20	12.06	0.05
Photographs			
11	18.27	6.94	0.01
47	22.33	11.50	0.05
Phantoms			
33	14.55	8.25	0.05
67	12.62	8.01	0.05

* $P \leq 0.05$ or greater is statistically significant.

estimation (negative skew) of stenosis severity for narrowings with > 50 %DS and underestimation (positive skew) of narrowings with ≤ 50 %DS can be seen by changes in skewing after training. The results of reduced skewing after training for increments of 10%, 25%, and 50% are shown in Table III.

The results of interpreting %DS from the 5 photographic reproductions are shown in Figure 4. Statistical differences before and after training were not detectable for these images, which had vessel edges and stenotic regions marked in both the pretraining and posttraining photographs. A reduction in reading variability was noted in 2 of the 5 (40%) arteries as shown in Table II.

Of the 6 phantoms interpreted, results improved in 5 of the 6 (83%) cases after training, with statistical ($P \leq 0.001$) improvement in 1 case,

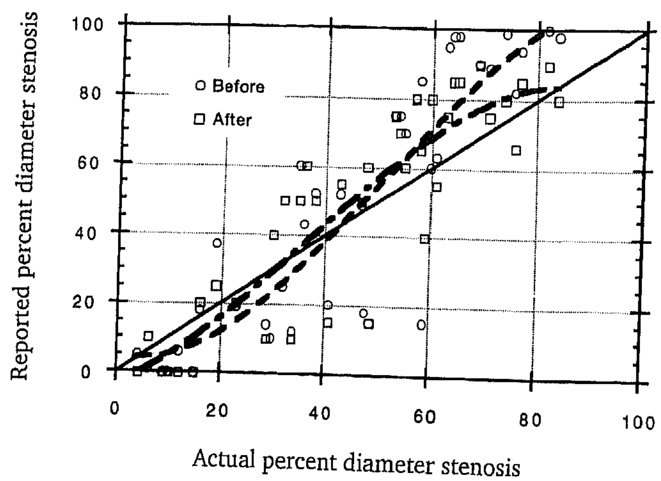


Figure 3. Percent diameter stenosis reported by a trainee. The open circles represent interpretation of percent diameter stenosis before training with open squares depicting results after training. The solid black line represents expected results if interpretation matches actual stenosis severity. The hyphenated (---) curve demonstrates the line of best fit before training, while the interrupted (-·-) curve represents improvement following training. Notice the reduction in overestimation of "severe" disease and underestimation of "less severe" disease after training.

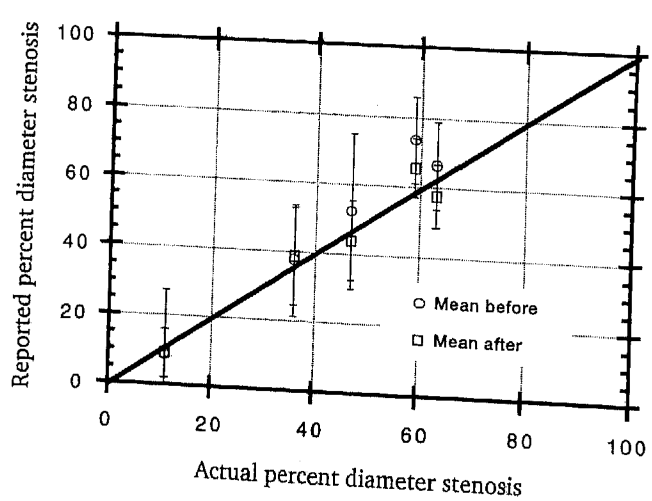


Figure 4. Percent diameter stenosis read from photographic reproductions of 5 stenotic arteries ranging from 11% to 63%. Results of the readings before (open circles) and after (open squares) training (y-axis) are plotted against actual percent diameter stenosis displayed on the x-axis. While improvement was noted in 80% of the cases, no statistical differences occurred since edges were outlined both before and after training, excluding edge detection as a potential problem.

Table III

Skewing of Percent Diameter Stenosis Before and After Training

Range of Percent Diameter Stenosis	Skewing Before Training	Skewing After Training
	10% Increments	
0–10	3.72	0.77
11–20	1.44	0.73
21–30	1.81	1.65
31–40	0.02	–0.50
41–50	0.05	–0.42
51–60	–0.66	–0.64
61–70	–1.43	–0.41
71–80	–1.19	–0.15
81–90	–3.65	–1.97
	25% Increments	
0–25	1.89	1.03
26–50	0.29	–0.04
51–76	–0.95	–0.66
76–100	–1.55	–1.21
	50% Increments	
0–50	0.66	0.38
51–100	–0.99	–0.71

as noted in Figure 5. A statistical reduction (Table II) in variability for phantoms with 33% and 67 %DS was noted after training.

Discussion

Interpretation of CAD with severity expressed as %DS has previously been shown to be extremely variable and not related to level of experience or training background.[1-5] When results of physicians, nurses, and students were compared before and after training, no statistical differences among groups could be detected, supporting the idea that there is currently no significant effect of training programs and no differences in the ability of various groups of individuals to learn how to accurately read CAs given this training program. All groups of individuals improved after training, without group differences.

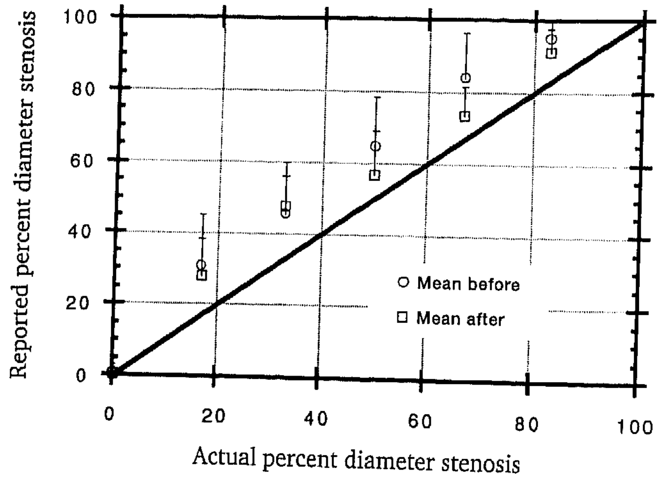


Figure 5. Interpretation of phantom stenoses before and after training. Six phantoms were interpreted before and after training with results reported as percent diameter stenosis. Results before (open circles) and after (open squares) training are plotted against actual percent diameter stenosis noted on the x-axis. Improved reporting of percent diameter stenosis was noted in 83% of the phantoms after training.

As previously predicted from data regarding patterns of interpretation[5] of CAs and the results of variables[6,7] comprising CAD, people read %DS based upon interpretation of image density, ie, brightness or darkness of the image. When photographed arteries were presented with edge detection already performed, no significant improvement could be detected after training, although there was a statistical reduction in the variability of %DS reported in 40% of the images. However, when phantoms and arteriograms were presented, without phantom and vessel edges being outlined, improvement in reporting %DS was seen in 69% of the arteriograms and 83% of the phantoms. As demonstrated by the reduction in skewing of the data, as well as by statistical reductions in errors and variability after training, the overall tendency to overestimate "severe" disease and underestimate "less severe" disease was significantly reduced as a result of this training program.

Such training should result in: (1) improved interpretation of severity of disease present in a given individual, (2) improvement in determining the potential benefit derived from interventional (mechanical, thrombolytic, etc) procedures, (3) decreased referrals for CABG in individuals who truly do not have three-vessel CAD, (4) improvement in comparisons of research studies,[8] and (5) an improved ability to define the physiologic limitations[6,7] of an individual patient based upon more accurate interpretation of %DS. Reductions in SFR perceived as exertional angina begin when %DS reaches 40%.[6,7] Rest angina occurs when flow cannot be increased above resting levels (SFR $\leq$ 1.0), which is known to occur when %DS reaches 70%.[6,7] Knowledge of this information, along with accurate interpretation of %DS from CAs, can allow clinicians to better predict the outcome of their patients, as well as provide incentives for life-style changes designed to reduce %DS through preventive cardiology techniques.

Conclusions

Although coronary arteriography has been performed for more than thirty years and angioplasty for more than fifteen years, the absence of a training program to accurately instruct physicians in the interpretations of CAs has had significant clinical implications for patient management. The development of this training program with standardized pretraining results and expected training outcomes provides a valuable tool for instruction of cardiologists, cardiology fellows, and other health care providers who have an interest in the clinical management of patients with CAD. Given the clinical limitations of the current approach used to read %DS from CAs, physicians who plan to evaluate CAD by cardiac catheterization should (1) undergo training to improve the accuracy of their interpretations, or (2) employ the assistance of health care providers who have undergone such additional training, or (3) depend upon the use of more expensive instrumentation designed to provide accurate assessment of %DS, to ensure the best possible outcome for patient care and management.

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