Diagnostic Value of Image Processing in Myocardial Scintigraphy

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The diagnostic value of stress myocardial analog scintigrams, and of five image-processing methods, was assessed by a decisional analysis in 96 patients undergoing coronary arteriography. The methods involved digitalization, nine-point binomial smoothing, background subtraction by linear interpolation, stationary filtering, and a combination of them. The difference between after-test probabilities of having the disease with a positive or a negative examination provided a discriminant index for different prevalences of the disease. Though the processing methods failed to improve the detection of a circumflex stenosis, the stationary filter significantly increased the diagnostic value for the detection of stenosis in a left anterior descending artery for a large range of prevalence, and in a right coronary artery at high prevalence. Thus, the filter seemed to provide a useful tool for enhancing the diagnostic value of myocardial scintigraphy.

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Exercise thallium-201 myocardial scintigraphy (ExMS) provides a well-established examination in the diagnosis of coronary disease (*1*). Some studies seem to indicate that the diagnostic value of analog images can be enhanced by a simple image digitalization with a display in color or a gray scale (*2,3*). The aim of this study was to assess the diagnostic value of different methods of processing of myocardial thallium images, some of which methods have already been used successfully in brain or liver scintigraphy (*4,5*). The comparison between the results obtained with analog images and those with processed images was carried out for 96 patients using a decisional analysis based on Bayes' theorem.

MATERIAL AND METHODS

Patients. Ninety-six subjects, 77 men and 19 women, with no prior history of infarction, were selected between 1978 and 1980 in a general hospital on clinical criteria suggesting coronary artery disease (CAD). Mean age was 54 yr, range 32 to 75. Informed consent was obtained in all cases. All patients had undergone exercise thallium-201 scintigraphy following a stress electrocardiogram. Positive diagnosis and topography of the CAD were established by coronary arteriography within a mean interval of 9 days.

Exercise myocardial scintigraphy. Stress testing was performed on an ergometric bicycle using 30 W increments. As long as the ECG remained normal, the test was continued until pulse rate reached 80% of the maximum theoretical value for the subject's age. It was stopped earlier if the patient was no longer able to continue (8%), if a fall in arterial pressure occurred (7%), or in event of anginal pain (9%) or ventricular tachycardia (1%). However, shift in the S-T segment was not considered grounds for stopping. At the peak of the exercise, 1.5 to 2 mCi of thallium-201 were injected intravenously, and the test was prolonged 1 min with a load of 30 W. Scintigraphy began 5 min after injection.

The study was performed using a gamma camera equipped with a high-resolution collimator, 32 cm in diameter, and linked to a 64K-word, 16-bit computer. The spectrometer was adjusted for the 69–83 keV x-ray from the mercury daughter with a 25% window. Four views were obtained in the supine position: anterior, left anterior oblique at 45° and 60°, and left lateral, each consisting of 350,000 events recorded on the output film. Images were stored simultaneously on disk in a 64 × 64 matrix. Delayed images were not systematically per-

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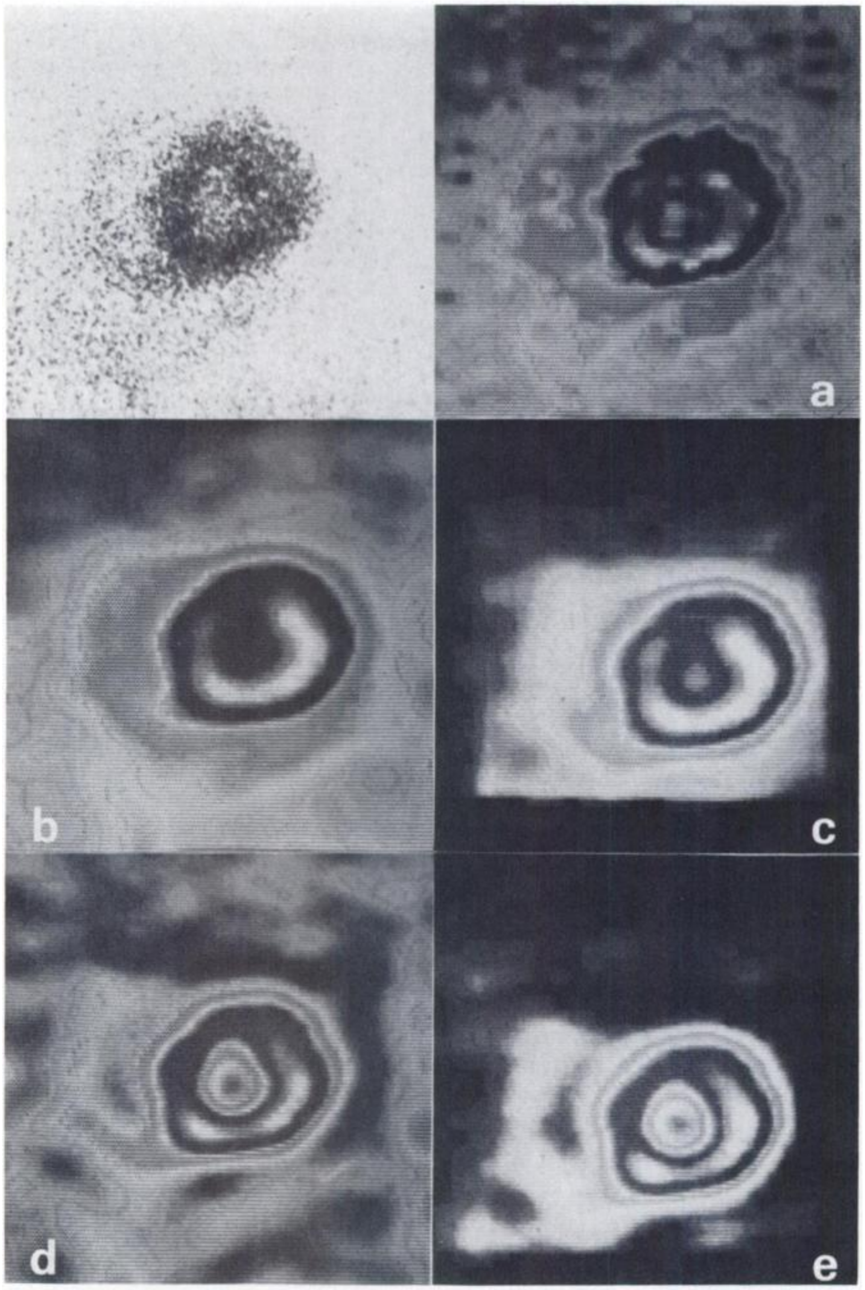

FIG. 1. Myocardial Tl-201 scintigraphy of normal subject in LAO view at 45°. (Ana) Analog, (a) digitalization, (b) binomial smoothing, (c) background subtraction by linear interpolation, (d) Canterbury filtering, (e) 'c' followed by 'd' filtering.

formed since the selecting criteria did not indicate myocardial infarction.

Coronary arteriography. We performed coronary arteriography and ventriculography by femoral catheterization. All views necessary to determine a lesion were performed and interpreted by two independent radiologists unaware of the scintigraphic results. Arterial stenosis was considered significant only if it exceeded 75% narrowing of the lumen (*6*). Lack of agreement in the interpretation led to a new angiographic reading.

Image processing. Images were processed according to five modes designated 'a', 'b', 'c', 'd', 'e' (Fig. 1):

'a': digitalization of the analog image;

'b': linear nine-point binomial smoothing;

'c': background subtraction by linear interpolation (*7*);

'd': linear stationary filtering, also called "Canterbury filtering" or "Unsharp masking" (*8*);

'e': background subtraction 'c', followed by 'd' filtering.

Lastly, all images were enlarged by extrapolation, eliminating most of the nonmyocardial regions.

Visualization. Initial analog images were recorded on black-and-white NMB Kodak film. The four views of each kind of processed image were photographed on color slide film from the TV screen. The color process

TABLE 1. VARIATION IN SENSITIVITY AND SPECIFICITY WITH IMAGE PROCESSING (IN PERCENT)

Type of analysis		Image processing: Analog	a	b	c	d	e
General	Se	75	63	40	77	96	96
	Sp	90	88	88	78	67	61
LAD artery	Se	55	45	28	55	72	74
	Sp	96	97	97	97	93	93
Circumflex artery	Se	48	21	5	21	30	26
	Sp	99	100	100	100	98	100
Right coronary	Se	62	48	30	69	81	88
	Sp	93	97	97	91	76	67

TABLE 2. DISCRIMINANT VALUE OF ANALOG AND PROCESSED IMAGES FOR THE PREVALENCE OF THE DISEASE IN EACH STUDY

Type of analysis	P(D+)	Image processing: Analog	a	b	c	d	e
General	0.72	0.53	0.41	0.26	0.47	0.75	0.72
LAD artery	0.63	0.52	0.47	0.38	0.53	0.61	0.62
Circumflex artery	0.43	0.69	—	—	—	0.57	—
Right coronary	0.47	0.62	0.61	0.51	0.64	0.57	0.57

was linear with 256 levels, scaled from blue to red from the lowest to the highest activity.

Method of interpretation. After a random selection of the slides, the six types of scintigraphic image were read independently by three observers (two physicians from a nuclear medicine department and a cardiologist trained in nuclear medicine) who were unaware of the results of the coronary arteriography. The reading of arterial irrigation territories was made according to the zones described by Cook (*9*). An examination was considered positive if hypofixation took place on two views for the same arterial zone. This system allowed us to classify the examinations as follows: true positive (TP: abnormal ExMS and coronary arteriography), false positive (FP: abnormal ExMS and normal arteriography), false negative (FN: normal ExMS and abnormal arteriography), true negative (TN: normal ExMS and coronary arteriography).

First, ExMS was classified as normal or not without taking into account the topographical location of the abnormality. This analysis, called "general," allowed us to define the probability of having CAD. Second, ExMS was considered as positive or not according to the coronary distribution of the myocardial walls on a scintigram. This analysis, called "regional," allowed us to define the probability of detecting a lesion for each artery.

Decisional analysis. For the six types of images, sensitivity (Se), specificity (Sp), and prevalence [P(D+)] were computed a posteriori, using data from the coronary arteriography. These three parameters allowed us to apply Bayes' theorem and thus to calculate the probability of a patient's being ill when the test was positive [P(D+/T+) or Predictive Value Positive] or negative [P(D+/T−) or 1-Predictive Value Negative, see Appendix].

The difference between these two functions $\Delta = P(D+/T+) - P(D+/T-)$ was calculated for all prevalences of the disease, such as that proposed by Hamilton (*11*). It represented a discriminant index of the test proportional to the number of exact detections of the disease. This index Δ, which is not a probability, reached a maximum less than one for a given prevalence and 0 for P(D+) = 0 and 1.

Graphs P(D+/T+), P(D+/T−), and Δ were drawn as a function of the prevalence for each method of imaging treatment and for general and regional analyses. Thus, processing methods were descriptively compared by the classification of the Δ indices obtained for the prevalence of the disease in the group under study. The Δ curves gave additional information on the value of the tests in the other ranges of prevalence.

The statistical value of this Δ classification was assessed by using a McNemar's statistic. That is, for each patient, matched or mismatched pairs of true or false results were formed for analog images compared with either 'a', 'b', 'c', 'd', or 'e' images (see Appendix).

RESULTS

Patients. Twenty-eight percent of the patients had no significant stenosis by coronary arteriography while 72% of the patients had CAD. A stenosis of one, two, or three coronary arteries was found in 19%, 25%, and 28% of these patients, respectively. The frequency of the impairment of the left anterior descending artery (LAD) was 63%, that of the right coronary was 47%, and that of the circumflex artery was 43%.

Sensitivity and specificity (Table 1). Results of the general analysis showed that digitalization and binomial smoothing decreased the sensitivity of ExMS. Other processing (such as filtering) sharply increased it but they decreased its specificity. The changes induced by the processing were similar in the regional analysis except for the detection of an impairment of the circumflex artery, for which the sensitivity of ExMS decreased with processing.

Discriminant values (Table 2). *General analysis.* In the population studied, the 'd' and 'e' filtered images gave a discriminant value significantly higher than that obtained with the analog image ($p < 0.03$), whereas all the other processing methods decreased or failed to improve

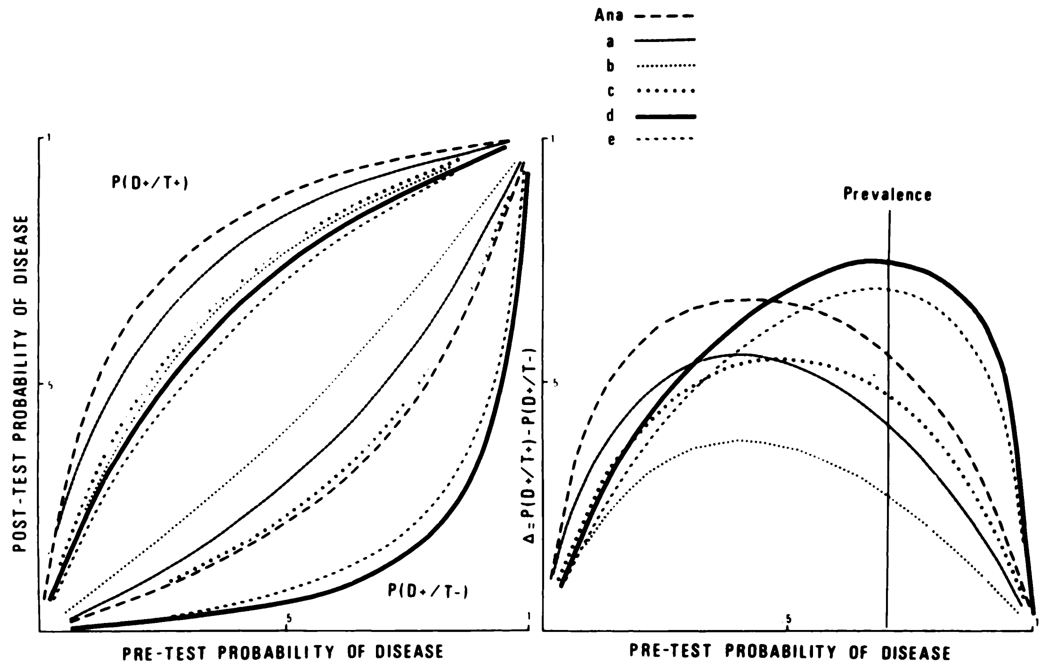

FIG. 2. General analysis. Left: P(D+/T+) is probability of having coronary artery disease with positive analog (Ana) or processed ('a', 'b', 'c', 'd', 'e') Tl-201 scintigram for various pretest probabilities (prevalences) ranging from 0.05 to 1; these curves are concave downwards. P(D+/T−) is probability of having coronary artery disease with negative test; these curves are concave upwards. Increase of probability of disease after positive test, and decrease of this probability after negative test, can be calculated from these curves. Right: influence of prevalence of disease on discriminant expression Δ. This value is optimum for "d" processing (Canterbury filter) at prevalence of disease in population under study (vertical line at 70%).

significantly the discriminant value of the test. Moreover, the Δ curve obtained with the 'd' filter crossed over that of the analog image as soon as the prevalence of the CAD exceeded 47% (Fig. 2).

Regional analysis: left anterior descending coronary artery. The 'd' filter, as in the previous study, and also the 'e' filter, gave discriminant values significantly higher than those obtained with the analog images for the impairment of the LAD in the study ($p < 0.01$). As soon as the prevalence of this impairment was 25%, Δ values of filtered images were greater than those of the analog images (Fig. 3).

Circumflex coronary artery. In this case of coronary impairment the filtered images are unable to improve the

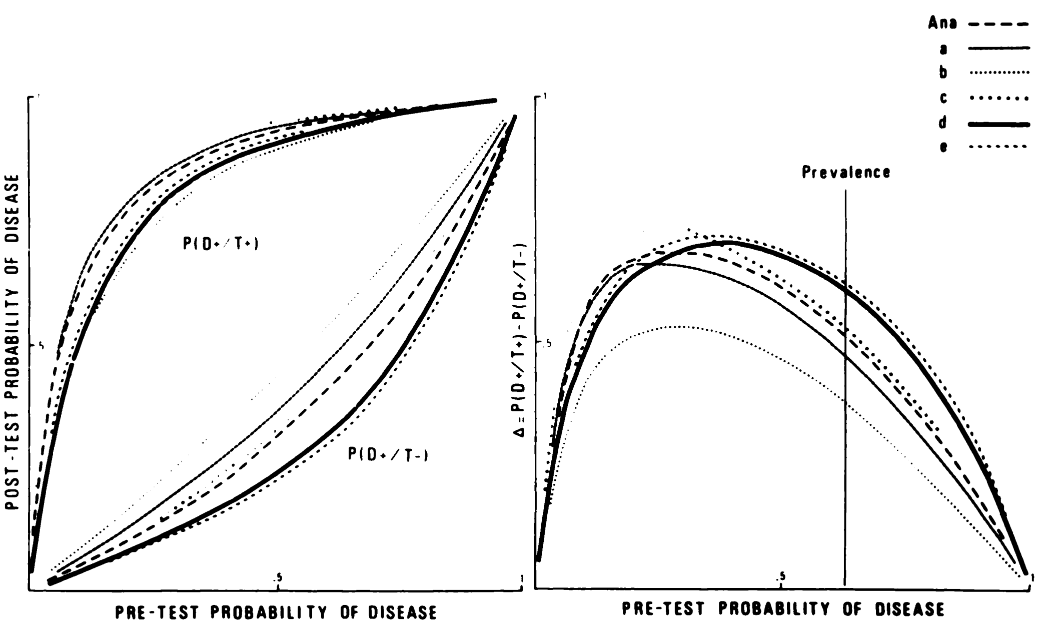

FIG. 3. LAD coronary artery analysis. Δ is optimum for 'd' and 'e' processing at prevalence of impairment of LAD in population under study (63%).

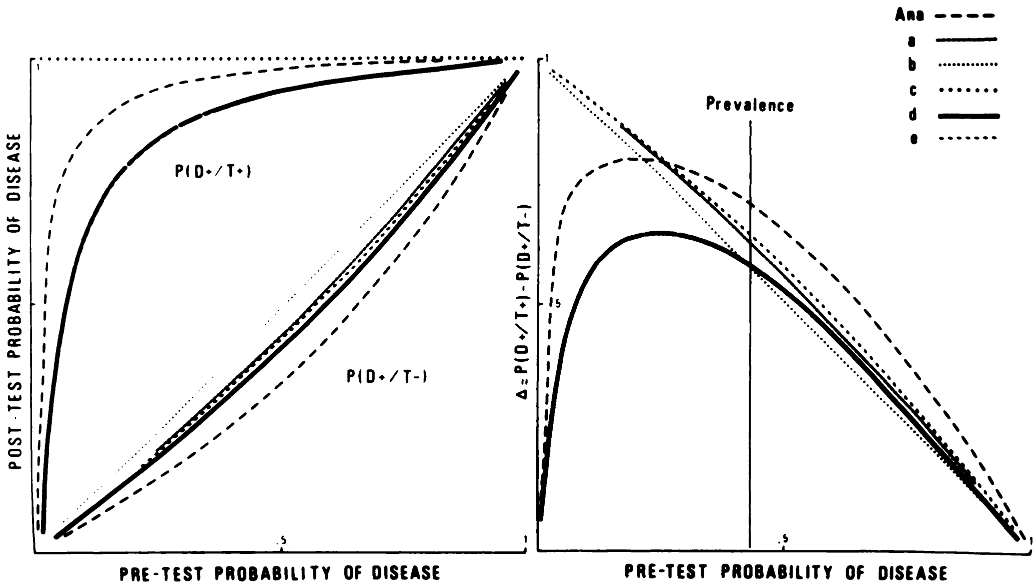

FIG. 4. Circumflex coronary artery analysis. Δ is optimum for "Ana" at prevalence of impairment of circumflex artery (43%).

Δ value of the test, whatever the prevalence. The discriminant values and curves for the other kinds of processing were obviously biased, since no false positives occurred in this type of study (Fig. 4).

Right coronary artery. For the prevalence of the right coronary impairment in the study, the filtered images were also unable to improve the Δ value of the test, like the other processing methods. Background subtraction 'c' seemed to provide a better discriminant value, but this was not significant. Nevertheless, for higher ranges of prevalence, Fig. 5 clearly showed that filtered images gave greater Δ values than the analog ones.

DISCUSSION

The results corroborate the well-known efficiency of analog thallium ExMS in the diagnosis of CAD (*1,12–14*), since sensitivity and specificity are close to the other values reported. The main point demonstrated by this study is that the diagnostic value of ExMS can be increased by image processing. A stationary filter (Canterbury filter) as described by Corfield (*8*) appears to give the best discriminant value among the differing processing methods as soon as the prevalence of the disease is higher than 47% (Fig. 2). It is also the best processing to enhance the detection of an LAD impairment if the prevalence of this impairment is higher than 25%.

Few data are available about the efficiency of image processing on ExMS. This is probably due to the difficulty of comparing different processing methods with regard to the diagnostic information they provide. As a matter of fact, the choice between different tests or processing is generally difficult to assess for two reasons. First, sensitivity and specificity of a test vary inversely with one another: should the optimal processing be the one for which the sensitivity provided is equal to the specificity, or greater or lower than the specificity? Second, a processing method may be suitable for a given population with a characteristic prevalence of a disease but might not be suitable for another population. A processing method that is optimal for too limited a range of prevalence cannot be of general value.

Decisional analysis can solve these difficulties. It allows the choice of the optimal processing method, since this analysis defines for each of them a single parameter that takes into account at one time the sensitivity and specificity as a function of prevalence: namely, the discriminant value, which is a valid measure for descriptively comparing treatments.

However, for this kind of Bayes' analysis to be applicable, the population under study must be unbiased. Under biased conditions, sensitivity and specificity obviously may vary with the population studied and the drawing of after-test probability curves thus may be applicable to a more limited range of prevalence. This could be the case if the sample to be studied is composed of subjects who are very ill, providing highly positive examinations at one extreme, and perfectly healthy individuals who will show totally negative examinations at the other extreme (*15*). A sampling of a large number of patients with coronary disease ranging from those with trivascular impairment to those without significant stenosis, or even in good health, was performed in this study, thus avoiding this bias.

The enhancement of the diagnostic value of the ExMS by the stationary filter for the detection of CAD can be explained by the characteristics of the filter with respect to the scintigram. ExMS provides an image with high-count-density image but significant background; the

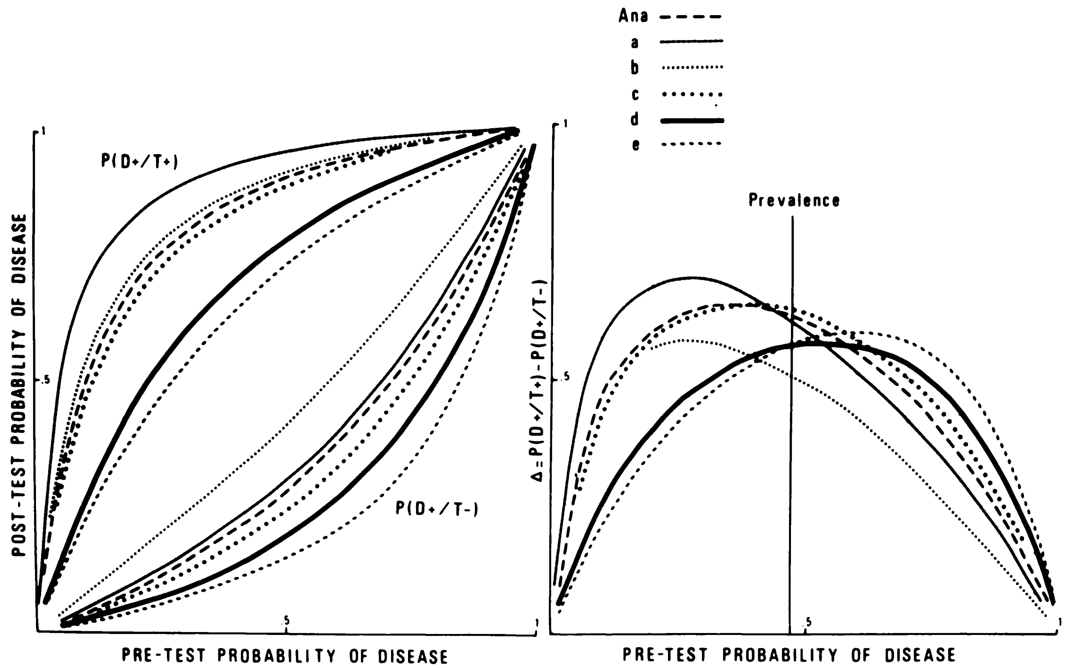

FIG. 5. Right coronary analysis. Δ is optimum for "c" at prevalence of impairment of right coronary artery (47%).

edges of a lesion are often difficult to recognize on an analog image. A Canterbury filter is a resolution-recovery filter that increases edge detection, as was previously shown for such high-count-density images as those of the brain (*4*) or liver (*5*). In addition, this filter allows a point-by-point background correction. Among the other processing methods, background subtraction by linear interpolation, proposed by Goris (*7*), slightly increases the efficiency of the stationary filter but not to a significant degree. However, this processing, applied separately, does not improve the diagnosis of CAD, probably because background increases abruptly near the hepatic region on the scintigram. Digitalization, as was previously shown by Eichstadt (*2*) and Wiener (*3*), reduces the resolution of an image by storing it in only a 64 × 64 matrix form. Binomial smoothing always decreases significantly ($p < 0.05$) the sensitivity and the diagnostic value of ExMS, and such processing is of interest only at low count density, as stressed by Wiener (*3*), Kuhl (*16*), and on a theoretical point of view by Pizer (*17*).

Although these statements are valid for the prevalences observed in our study, the analysis of Δ curves provides a simple means of extending them to the most nearly related prevalences. It is clearly shown on the curves (Fig. 2), that the Canterbury filter increases the diagnostic value of ExMS for detection of CAD, not only at the prevalence of our study (72%) but also for a range of prevalence between 47% and 100%. Such a prevalence variation, exceeding ±20% with respect to the composition of the studied population, is unlikely to be found from one cardiac patient to another. It suggests that this method of processing may be applied even with a rough a priori estimate of the prevalence. In fact, in every day practice, prevalence is not known a posteriori, but can be estimated a priori from clinical data and from rest or stress electrocardiographic findings (*18*). Similar conclusions can be drawn for impairment of the LAD and the right coronary when the prevalence exceeds, respectively, 25% and 55%. The anatomical characteristics of the circumflex artery can explain the failure of the 'd' filter to enhance the value of the test, whatever the prevalence may be. As the matter of fact, the posterior wall provides a low-count-density image because of tissue attenuation at the low-energy emission of thallium. Thus, the stationary filter is not suitable, and the detection of an impairment of the circumflex artery remains difficult, as was previously shown by Rigo et al. (*13*) and Lenaers et al. (*14*) with analog images.

We conclude that the diagnostic value of thallium-201 myocardial scintigraphy for the assessment of CAD or an impairment of the LAD (the most frequently impaired of the coronary arteries) is increased by processing with a Canterbury filter. It is also true for the right coronary artery if the prevalence of its impairment is high. Conversely, the other processing methods used in this study seem of little interest in the detection of lesions of the coronary arteries. These conclusions are based on a study of patients from a hospital population, with a high a priori probability of disease. Although the Canterbury filter can be applied efficiently for a large range of prevalence, the results of this study imply that, for the optimal application of this processing method, the user should estimate the a priori prevalence of the disease by means of clinical and electrocardiographic observations.

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APPENDIX

Different criteria were expressed:

Sensitivity: Se = TP/(TP + FN)

Specificity: Sp = TN/(TN + FP)

Prevalence:

$$P(D+) = \frac{\text{Number of subjects with stenosis}}{\text{Total number of subjects studied}}$$

The probability of a correct diagnosis (existing illness: D+) when the examination was positive (T+) was:

$$P(D+/T+) = \frac{Se \times P(D+)}{Se \times P(D+) + (1 - Sp) \times [1 - P(D+)]}$$

The probability of a wrong diagnosis (existing illness: D+) in spite of a normal examination (T−) was:

$$P(D+/T-) = \frac{(1 - Se) \times P(D+)}{(1 - Se) \times P(D+) + Sp \times [1 - P(D+)]}$$

The discriminant index was computed:

$$\Delta = P(D+/T+) - P(D+/T-)$$

Statistical analysis:

The mismatched pairs of results were tested by chi-square test for a binomial distribution (*19*)

$$\chi^2 = \frac{(N - M)^2}{N + M} \quad \text{if } M + N \geq 10$$

$$\chi^2 = \frac{(N - M - 1/2)^2}{N + M} \quad \text{if } M + N < 10$$

M is the number of pairs with incorrect analog readings and correct processed readings. N is the number of pairs with correct analog readings and incorrect processed reading.

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