The influence of viewing conditions on observer performance in dental radiology

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Observer performance under different viewing conditions was monitored by means of radiographs, showing (a) teeth with approximal caries, (b) teeth with simulated approximal caries, and (c) Plexiglas phantoms. Series *a* and *c* were exposed at two different exposure times, thus obtaining a dark and a light set of radiographs. The series *a*, *b*, and *c* were read by 11, 2, and 5 observers, respectively. All radiographs were examined under two viewing conditions on different occasions as follows: ceiling light in a room without a window, and X-ray viewer (×2 magnification) with two alternative light sources. Diagnostic quality, measured as the ROC area, showed small variations in accordance with viewing conditions. For dark radiographs the X-ray viewer improved diagnostic quality compared with the viewing against ceiling illumination; however, room illumination provided the best viewing conditions when light radiographs were examined. Most of these differences were not statistically significant ($p > 0.05$). Only small differences in diagnostic strategies (cut-off points) were recorded between viewing conditions. □ *Dental caries; receiver operating characteristic (ROC) analysis; visual perception*

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Textbooks in dental radiology emphasize the importance of optimal viewing conditions during the examination of dental radiographs (1–3). Many papers that have focused on radiographic film interpretation conclude that viewing conditions may be of significance to visual detection (4–11). However, most frequently phantom lesions radiographed on extraoral (5, 9, 10, 12) or intraoral film format (13, 14) have been used in studies of viewing conditions. Only a few studies have used dental caries or artificially created dental lesions as test pathological material, and the results from these studies do not confirm that viewing conditions play a crucial role in diagnosis of caries on radiographs (15, 16).

According to Leijon (17), the viewing of dental radiographs should be performed under the following conditions: adjustable viewing light; mounted films; masking for extraneous light; film reflexes should be avoided; and a ×2 magnifying lens should be used. However, it is reasonable to assume that these requirements are not met in most dental practices, although most dentists seem to have a viewing box (18, 19).

Welander et al. (14) claim that clinicians who view radiographs under less than optimal viewing conditions 'are compromising their diagnostic efficency'. In this study the perceptibility, which was defined as the number of phantom radiolucencies recorded (20), was improved when using masked frames or a viewer. Viewing against the ceiling light or a viewing box with no masking of extraneous light decreased the perceptibility.

Some data indicate that density of films processed in dental practice may vary considerably even within the same practice (21). It has been shown that the density of radiographs affects interpretation and that radiographs of low density seem to require other viewing conditions than high-density ones (14, 16).

There is a need for consistent criteria for diagnosis and therapy among dentists (22). Variation in viewing conditions and film density may affect the application of diagnostic

criteria and the quality of radiographic diagnosis. This study was carried out to measure observer performance and to quantify diagnostic quality when different viewing conditions and film densities were used.

Materials and methods

Observer performance under two viewing conditions was assessed in this study. The first condition consisted of using the ceiling light in a room without window. The average level of illumination at the plane was about 215 lx (Hagner photometer). The second alternative consisted of using two alternative viewboxes with luminance of about 4800 lambert and 100,000 lambert (Phillips Densoscope). Radiographs were read in a darkened room, and the observers were asked to use the low-intensity viewbox routinely, and Densoscope when more intense light was necessary. A viewer with a ×2 magnification lens (X-Produkter) was used by the observers under the second condition.

Three series of radiographs with different types of images were examined under the two viewing conditions with at least 2 weeks' interval.

Radiographs of 60 approximal surfaces constituted series 1. On the basis of direct inspection and probing the surfaces were classified as sound ($n = 23$) or carious ($n = 37$). When a break in the outer enamel was detected, the surface was classified as carious, otherwise sound. The films in series 1 were interpreted by 11 dentists.

Series 2 consisted of 236 radiographs of 13 extracted teeth that originally had no caries or defects. By using a diamond bur (diameter, 1 mm) artificial lesions extending to the dentinoenamel junction were made in the most prominent part of the approximal surfaces. Several exposures were made of each tooth, and the relative mineral loss of the lesions was changed between each exposure by a technique that is more fully described elsewhere (23). Radiographs were also taken before preparation of lesions, and these images served as negative controls ($n = 109$). Two dentists diagnosed series 2.

Series 3 contained radiographs of 25 Plexiglas phantoms. The phantoms were square blocks measuring $30 \times 40\ mm^2$ and 35 mm high. Holes or cylinders were randomly placed in up to four fixed positions on these blocks. Thus the number of 'signals' or phantom lesions varied from 0 to 4 on each film. The radiographs ($n = 25$) contained 20 sites with images of holes and 29 of cylinders and 51 negative controls. The diameter of the holes and cylinders was 9 mm and the depth/height ranged from -9 mm to $+12$ mm. Series 3 was interpreted by five observers.

Series 1 and 3 contained two sets of radiographs showing the same images. The only difference between the sets was film density, which varied with exposure time. Thus two series, which are termed 'light' or 'dark' in the text, were obtained.

Density measurements were performed with a Macbeth TD502 densitometer, and the film density of tooth images was measured just in dentin, just beyond the dentinoenamel junction. A positive D-value denotes a radiolucent phantom lesion, and a negative value a radiopaque phantom lesion. Radiographs in series 1 had a mean density of 0.5 and 1.1 for the light and dark images, respectively. In series 2 the corresponding density was 1.3. The phantoms in series 3 had mean background densities of 0.7 (light pictures) and 1.9 (dark pictures). The density values for the relative object contrast ranged from 0.00 to -0.05 (median, -0.02) and from 0.00 to 0.04 (median, 0.01) for the light pictures. For the dark radiographs the corresponding values ranged from -0.01 to -0.23 (median, -0.07) and from 0.01 to 0.13 (median, 0.03).

Analytical methods

The confidence ratings were sorted into decision matrices in accordance with the true state of the lesions to be diagnosed. The findings were then analyzed in accordance with the receiver operating characteristic (ROC) technique as described by Swets & Pickett (24), using a computer program developed by Dorfman & Alf (25), which fitted binormal ROC curves to the pooled observer scores by maximum likelihood estimation. The diagnostic quality was measured

by using the area beneath ROC curves, A_z, and diagnostic strategies were analyzed by using the parameters Z_k and β. Z_k is the frequency of overscoring at the operating point, given in normal deviate values from the bivariate normally distributed ROC graph. β denotes the slope of a tangent to the curvilinear ROC curve at the operating point. The β value indicates the observers' relative weighting of the cost of additional false-positive (FP) scores versus additional false-negative (FN) scores (26). The computational formula applied to draw the curves of the constant β was:

$$\beta = B \exp\{\tfrac{1}{2}[(1 - B^2)Z_k^2 + 2ABZ_k - A^2]\},$$

where A is the Y intercept of the bivariate normally distributed ROC curve, and B is the slope of the bivariate normally distributed ROC curve (24). In Fig. 1 are shown two theoretical ROC curves with identical slope (B) and two iso-β curves ($\beta = 2.0$ and $\beta = 0.5$). See Fig. 1 legend for further details. The iso-β curves were computed by using the averaged B-value of the ROC curves in the respective figure.

Results

The quality of diagnosis showed small variations with regard to the viewing condition. The area beneath ROC curves is a parameter

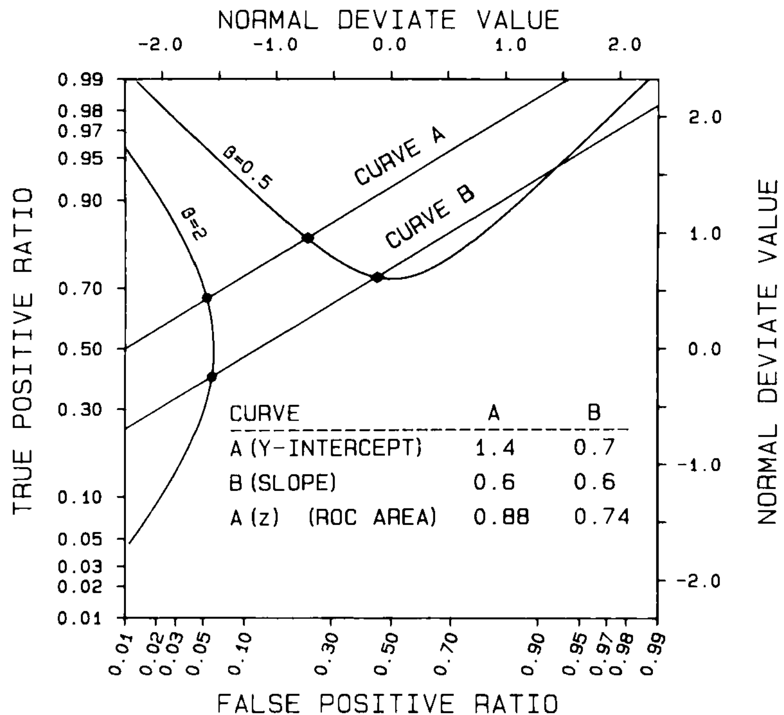

Fig. 1. Empirical ROC curves that are plotted on a binormal graph usually fit straight lines (curves A and B). The normal deviate values of true-positive and false-positive proportions are scaled linearly on the ordinate and on the abscissa, respectively. The scoring along the ordinate and abscissa is given in normal deviate values, and the corresponding probability values are noted. The closer to the upper left corner the curve is positioned, the better is the quality of diagnosis. Area beneath ROC curves is a single parameter of diagnostic quality, and actual values are given in the figure. Iso-β curves for $\beta = 2.0$ and $\beta = 0.5$ are drawn for comparison of diagnostic strategies. The β value reflects the observer's weighting of relative costs of mistakes (the cost of additional false-positive errors versus the cost of additional false-negative errors) in his reading. The filled circles represent cut-off points on curves A and B where the observer considers the costs of overcalling twice the costs of undercalling, and the filled squares represent the opposite observer weighting. The ROC curves are not fully described by the A_z value, but the paired parameters A (Y-intercept) and B (slope) give a complete description of the binormal ROC. In this paper, however, the single parameter A_z is used because it gives a more convenient representation of the diagnostic quality for comparison purposes.

Table 1. Quality of radiographic caries diagnosis obtained under different viewing conditions given by the area beneath ROC curve, A_z, with standard error in parentheses. The calculations were based on pooled scores from 11 dentists. NS denotes no statistically significant difference between viewing conditions ($p > 0.05$)

Film density	Viewing condition		
	Room lighting A_z		Viewer A_z
Dark radiographs ($n = 60$)	0.919 (0.014)	NS	0.923 (0.011)
Light radiographs ($n = 60$)	0.836 (0.027)	NS	0.813 (0.024)

Table 3. Efficiency of observer detection of phantom lesions in a Plexiglas phantom. A_z denotes area beneath ROC curve, and standard error is given in parentheses. Pooled scores from five observers were used. S = difference statistically significant ($p < 0.001$); NS = difference not statistically significant ($p > 0.05$)

Film density	Viewing condition		
	Room lighting A_z		Viewer A_z
Dark radiographs ($n = 25$)	0.909 (0.018)	S	0.994 (0.002)
Light radiographs ($n = 25$)	0.862 (0.024)	NS	0.791 (0.029)

of diagnostic quality and the values are given in Tables 1–3. For the dark radiographs the X-ray viewer and a viewing box improved diagnostic quality compared with viewing against ceiling illumination (Tables 1–3). The differences were only statistically significant when Plexiglas phantoms were detected ($p < 0.001$) (Table 3). In contrast, when light radiographs were examined, room illumination provided the best viewing conditions, but the differences were not statistically significant ($p > 0.05$).

Figs. 2–6 show pairwise ROC plots representing observer performance under the viewing conditions that were compared. Figs. 2 and 3 indicate only small, statistically non-significant differences in observer performance between the viewing conditions when dental caries was diagnosed. The corresponding cut-off points did not differ significantly between viewing conditions ($p > 0.05$). When different film densities were compared, the position of the cut-off points indicated that a stricter diagnostic threshold was applied when the light radiographs were interpreted (Figs. 2 and 3). This tendency was statistically significant in most comparisons between corresponding curve points ($p < 0.05$). Fig. 2 shows that the cost of additional FP scores is valued more than five times the cost of additional FN scores when light radiographs are interpreted by using an X-ray viewer. This relative weighting between additional FP and FN scores decreased to about three when ceiling illumination was used. When dark radiographs were interpreted, this value was about three under both viewing conditions (Fig. 3). Scores 4 and 5 were pooled and used as the actual cut-off point of most clinical relevance in these comparisons.

Table 2. Diagnostic quality in identification of simulated caries lesions (236 radiographs). A_z denotes area beneath ROC curve, and standard error is given in parentheses. Pooled data from two dentists. NS = difference not statistically significant ($p > 0.05$)

Viewing condition		
Room lighting A_z		Viewer A_z
0.700 (0.025)	NS	0.729 (0.024)

Discussion

This study indicates that viewing conditions are not critical for the quality of radiographic caries diagnosis, although the importance of masking and/or magnification is usually stressed in the literature (1–4, 7, 8, 13, 27). The present results did not confirm that an X-ray viewer with an ×2 magnifying lens always provides optimal viewing conditions. However, when the film is relatively dark, it was shown that masking of extraneous light might be important. An appropriate viewing condition for clinical use seems to be adjustable viewing light in combination with a

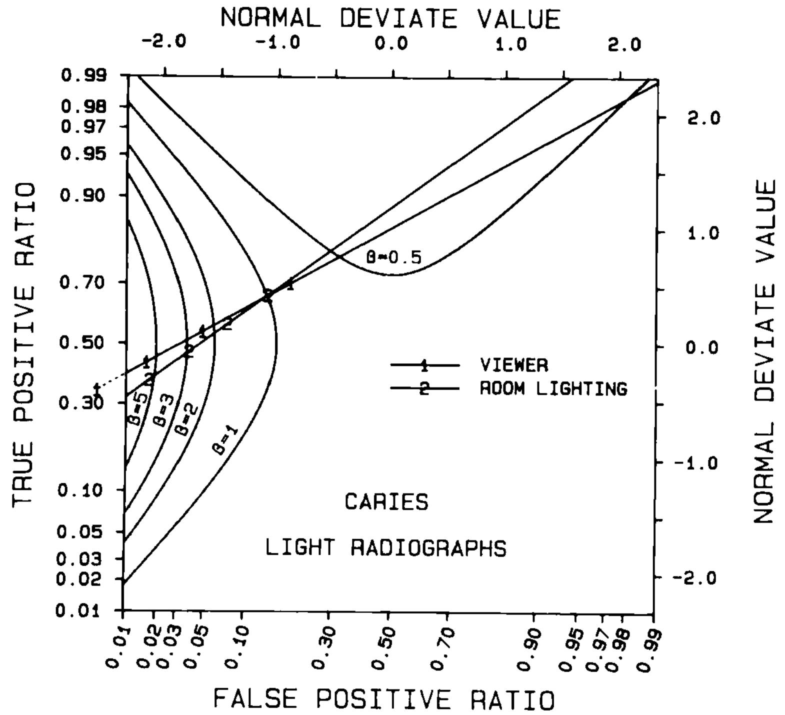

Fig. 2. Binormally fitted ROC curves for comparison of radiographic caries diagnosis under two different viewing conditions using light radiographs (series 1). Fig. 1 legend gives more detailed information about the ROC method. The A_z values are given in Table 1.

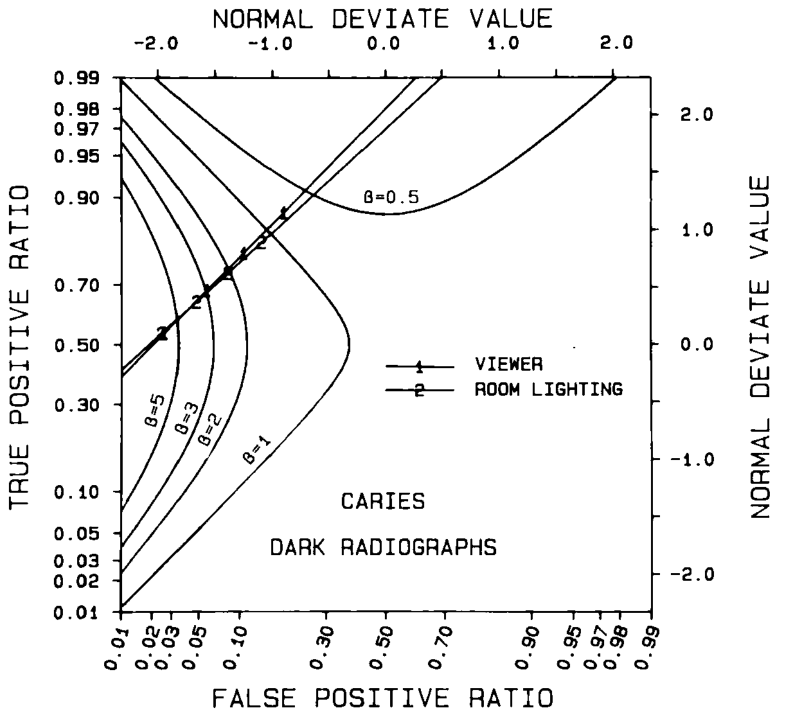

Fig. 3. Observer performance when caries is diagnosed radiographically, using fairly well blackened films ('clinical' judgement), is indicated by one binormal ROC curve for each setting. Fig. 1 legend gives additional information; see also Table 1.

viewing box for masking and magnification purposes. The light transmitted through the film should be brought to a level that is best perceived by the eye (3). This may explain the fact that overhead room light of low intensity turned out to be at least as effective as an X-ray viewer and high-intensity illumination when low-density radiographs were interpreted. These results are partly confirmed by other investigators (12, 16).

Merrild-Hansen & Ratjen (12) used simulated defects, which were radiographed on $24 \times 30\,cm^2$ films. The films were examined at a distance of 50 cm by four observers. Within the film densities examined (relatively light) and luminance used (540 to 10,800 lambert), they concluded that glare was of little importance.

Arnold (16) examined the influence of illumination and the use of accessories on radiographic detection of drilled approximal defects in tooth-like phantoms. He used 10 observers. He concluded that it might be an advantage to interpret light radiographs against the light of a window, which is in accordance with the findings of the present study. His general conclusion was that the best viewing conditions were provided in a semi-darkened room with a viewbox with high illumination and good masking against scattered light and that variation in illumination conditions had only small influence on detection. On the other hand, he found that a magnifying glass (×5) or an X-viewer (×2) produced a significant improvement in detection.

Mileman (15) confirmed that the effect of different viewing illumination levels was of minor clinical importance. His study was based on bitewings that were interpreted by 12 dental teachers. Inter- and intra-observer variation seem to be more important sources of diagnostic variation than different viewing conditions (15, 16).

An observer's thinking about the diagnosis and therapy might be affected by his feelings about diagnostic accuracy. For instance, if he subjectively judges the viewing conditions and/or film density not to be optimal, it is reasonable to expect that he will take precautions by consciously or unconsciously adjusting the diagnostic threshold. The results indicated that the diagnostic quality did not differ substantially and that viewing conditions did affect the relative costs that were associated with incorrect decision outcomes (FP and FN scores). The viewing against ceiling light using dark radiographs seemed to increase the relative cost of additional FN scores compared with additional FP scores, whereas the opposite observer performance took place during the examination of light radiographs, as indicated in Figs. 2–6.

Detection of low-contrast lesions is affected by viewing conditions. This is demonstrated by using the test image provided by Ravindra et al. (28). Their conclusion was that extraneous light peripheral to an image decreases visual sensitivity. By creating subtle phantom lesions (series 3) a situation was created in which diagnostic quality depended on viewing conditions. However, when clinically relevant radiographs showing dental caries were examined, the effect of viewing conditions was overshadowed by film density effect. It is therefore reasonable to raise the question of how relevant it is to extrapolate results from general perception studies and make general recommendations for examination of dental radiographs, without taking into account variables like film density and type of pathologic condition.

Incipient caries in approximal enamel has a radiographic outline that is relatively often recognized by a trained observer (29). It has been shown by means of digitized radiographic displays showing approximal caries that the amount of quantum noise in the image could be increased substantially while maintaining a comparable diagnostic performance (30).

Most studies that assign a significant influence to the viewing conditions are based on phantoms with no similarity to the clinical situation (5, 9, 10, 12–14). Some of these studies deal with borderline lesions that are hardly visible. The relevance of focusing on, for instance, viewing conditions and not on the observer error, which in general plays an important part in diagnosis (31), might be questioned.

Quantitative assessment of diagnostic quality is necessary to compare observer performance under different conditions. Some

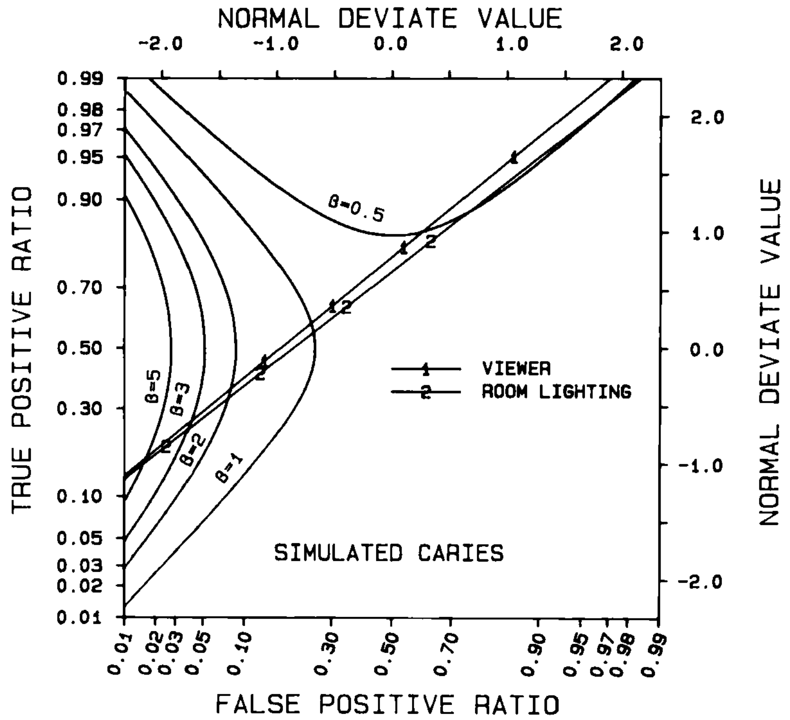

Fig. 4. Binormal ROC plots indicating observer performance for radiographic examination of simulated carious lesions under different viewing conditions. See Fig. 1 legend for further explanation; Table 2 shows an index of diagnostic quality.

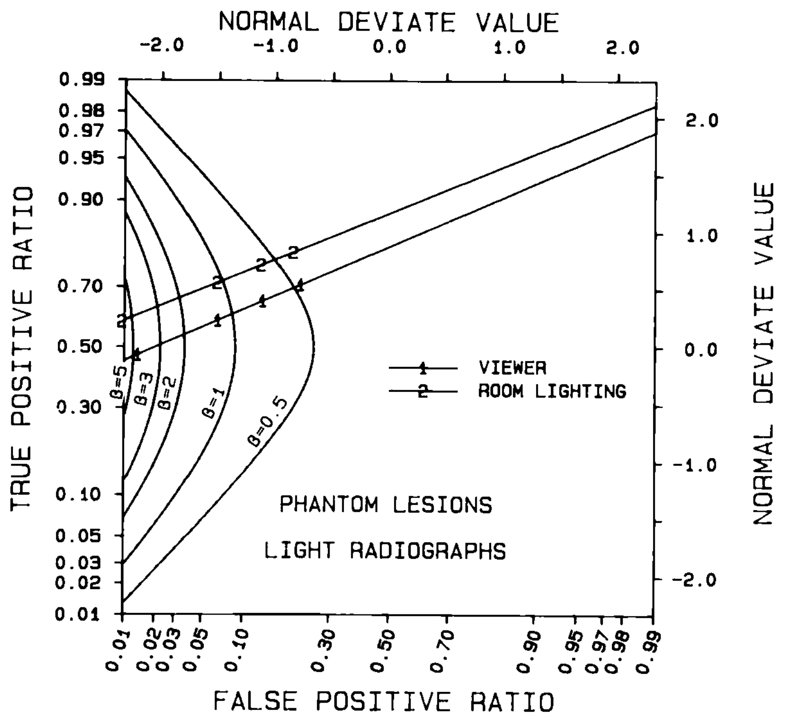

Fig. 5. Phantom lesions diagnosed on light radiographs under two viewing conditions gave these binormal ROC curves. See Fig. 1 legend for further information. Table 3 gives a parameter of diagnostic quality which is based on the actual ROC curves.

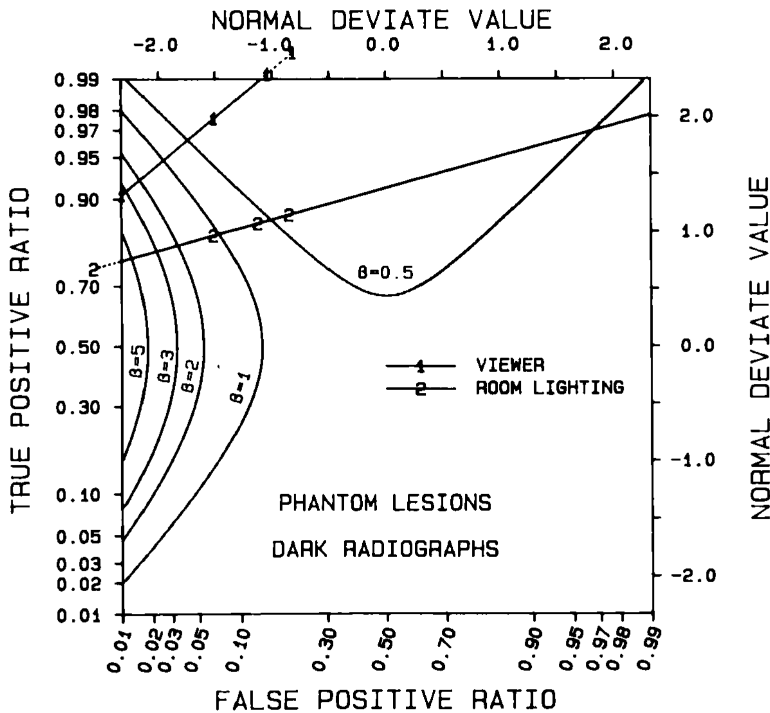

Fig. 6. Phantom lesions diagnosed on fairly well blackened films (visual judgement). The ROC graph indicates observer performance under two different viewing conditions; a further explanation is given in Fig. 1 legend. See also Table 3.

studies use test patterns and monitor the number of positive registrations (5, 9, 13, 14, 16) or fraction of true-positive registrations (10). In one study consistency was measured (15). These criteria cannot separate differences between two systems, since they do not take into account changes in decision criterion and diagnostic performance. Usually, diagnosticians do not want to identify pathologic condition at any price. The price may be a lot of FP registrations. Observers might desire to minimize the errors by weighting the pay-off and balance the over- and under-scoring (24). The expected value of a decision may change in accordance with the knowledge and experience about the importance of film density and viewing conditions. By using the ROC technique, it is possible to obtain an estimate of diagnostic quality which is not biased by changes in diagnostic threshold (24). The ROC analysis of observer performance has been the commonest approach to studies of lesion detectability (32).

The present findings suggest that the viewing requirements needed in dental radiography depend on the subject of interest and the density of the film. Studies based on subtle and hardly visible phantom lesions do not always give reliable results that are relevant to the clinical situation.

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