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LESION CONSPICUITY, STRUCTURED NOISE, AND FILM READER ERROR

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ABSTRACT:

The concept of conspicuity is introduced in an attempt to objectively quantitate radiographic observational error. Defined as a ratio between lesion contrast and surround complexity, the measure correlates well with the probability of detecting faint nodular lesions in chest radiographs. The concept helps in understanding why abnormalities are missed by radiologists. It is also used to explain why image-processing techniques advocated in the past did not yield improvements in diagnostic accuracy and to outline directions for the future. Preliminary results are presented which show that photographic subtraction can increase the conspicuity of simulated early lung lesions and improve their detection.

INTRODUCTION

The visibility of a lesion such as a nodule on a chest film depends not only on the physical properties of the lesion such as size, shape, and density but also on the properties of the structures that surround it. For example, contrast is a joint property of the lesion and the surround: the greater the difference in density between the two, the greater the visibility. Additional factors affect visibility. One is the complexity of the normal anatomic structures that form the surround or background of the lesion. In the chest, this structural complexity is due for the most part to ribs and blood vessels. A commonly encountered example of structural complexity obscuring a lesion is the pulmonary nodule that is superimposed on the vascular shadow of the pulmonary hilum. The effect of structural complexity is illustrated in figure 1*A*, where four nodules of identical size, contrast, and edge sharpness were photographically superimposed on a chest film. Figure 1*B* was included to verify the presence and location of the nodules and was made by photographically subtracting the original normal film from the same film containing the simulated nodules.

Clearly, the nodule in the upper part of the right hilum is less visible than the one in the left upper lung, while the other two are intermediate in visibility. It seems logical to assume that the probability of detecting the lesion in the left upper lung is greater than the probability of detecting the nodule in the upper right hilum.

DEFINITION OF CONSPICUITY

To explore the relationship between the probability of detection of a nodule on the chest film and the complexity of the normal structures that surround it, a quantitative measure called conspicuity was developed [1]:

$$\text{conspicuity} = \frac{\text{lesion contrast}}{\text{surround complexity}}. \quad (1)$$

The technique for measuring complexity has been described [1]. In brief it consists of making a series of densitometric measurements with a small aperture (1 mm) along the inside and the outside of the border of the lesion. The density change *across* the lesion border is used to calculate contrast, and the rate of fluctuation of the density *around* the lesion border is used as a measure of complexity.

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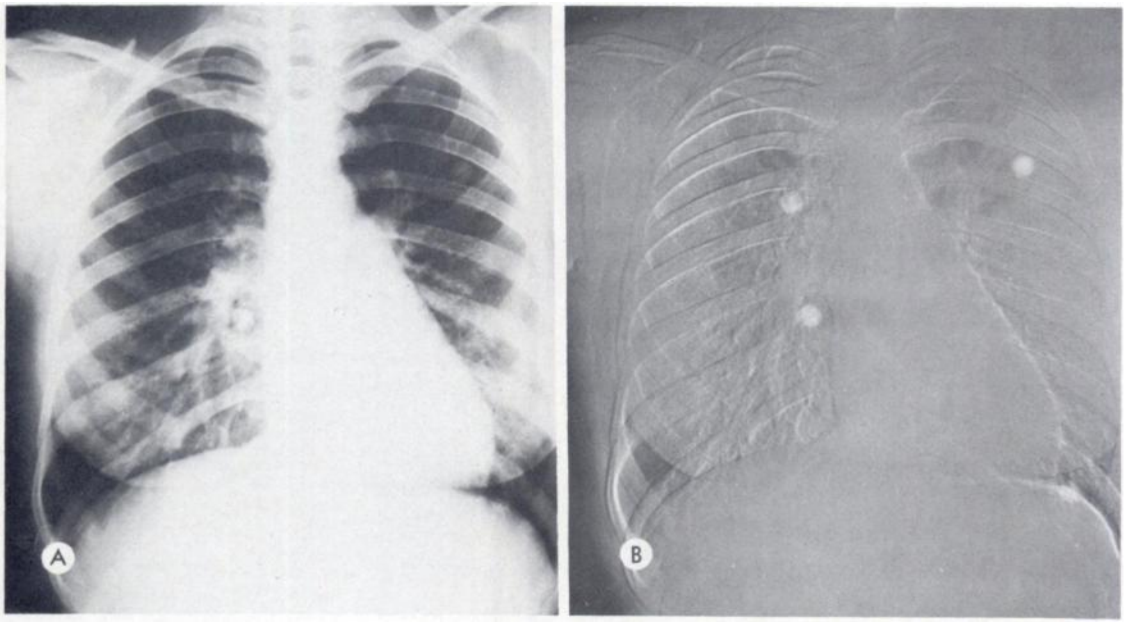

FIG. 1.—*A*, Chest film produced by superimposing grey mask containing four nodules of identical size, shape, and contrast. *B*, Result of subtracting original film from film with superimposed nodules.

To study the relationship between detection and conspicuity, the numerical value of conspicuity was measured for lung nodules on 25 different films. After 25 normal films were added to the series, they were shown in random sequence to 10 film readers who were asked to determine the presence and location of any nodules. Based on the responses, the probability of detection was calculated for each nodule. For the purposes of this experiment, false positives were neglected. A plot of the probability of detection $P(d)$ against the logarithm of conspicuity K is shown in figure 2. The logarithmic relationship seems to hold over a range of conspicuities from 0.5 to 1.5. That is, in a first approximation

$$P(d) = C(\log K), \tag{2}$$

where C is a constant. Equation (2) is not complete. Factors such as size, the resolving ability of the human eye–brain system, the total background luminance, and factors related to visual search must be included. A more complete equation is in development. The purpose of this discussion is to present the concept of conspicuity and relate it to detection.

IMPROVING FILM READER ERROR

The study of conspicuity was undertaken to develop a rational basis for the use of image processing in radiology. Error rates are known to be high in reading chest films, approaching 30% in surveys for tuberculosis [2] or lung cancer [3]. Image processing techniques such as contrast enhancement, edge enhancement, density-to-color conversion, and others have been uniformly unsuccessful in improving error rates [4]. In our opinion, the importance of the structures that surround a lesion has not been recognized during picture processing. When using contrast or edge enhancement, the contrast or edges of both the lesion and the background structures are affected. If they are affected equally, conspicuity remains unchanged; if surrounding complexity increases faster than contrast, conspicuity will actually decrease. The latter appears to be what generally happens.

Engineers discuss this problem in terms

of signal and noise. Equation (1) is analogous to a signal-to-noise ratio except that the noise is not the traditional random graininess or mottle seen in images but rather consists of structures that interfere with the visibility of the signal. Therefore we have referred to this as structural noise [1].

The image processing problem now becomes one of either selectively enhancing contrast or selectively reducing structural complexity. The use of contrast material is an example of a technique to produce images with enhanced contrast, while planigraphy is a technique to decrease structural complexity. Subtraction is an image processing technique to reduce structural complexity or structural noise [4].

Reducing Structured Noise by Subtraction

Photographic subtraction is used increasingly in angiography: a preliminary film is subtracted from a film made after the injection of contrast material. Both films contain identical anatomic structures (structural noise), but the postinjection film also contains the contrast-filled vessels (the signal). Subtraction will then reduce complexity without affecting the signal contrast. Angiography is an ideal field for use of this technique because the major condition necessary for good results can be met, namely, accurate anatomic registration between the two films being subtracted. The structures to be subtracted must superimpose precisely to achieve good results, and in an angiogram with rapid serial filming this is possible.

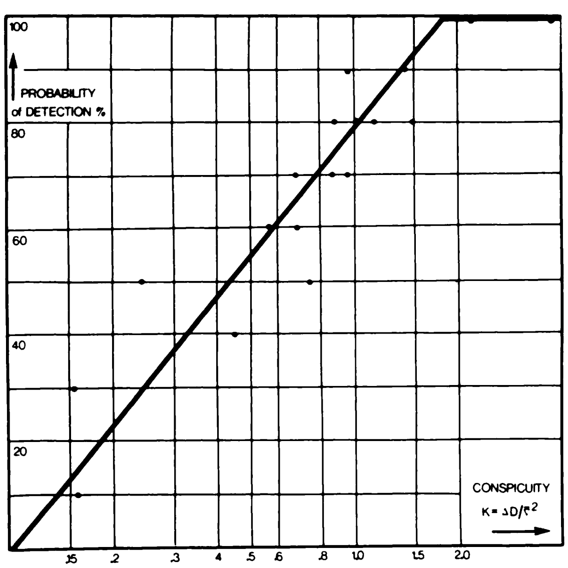

FIG. 2.—Probability of detecting nodule on chest film plotted against conspicuity on semilogarithmic scale. (Reprinted with permission from Revesz G, Kundel HL, Graber M: The influence of structured noise on the detection of radiologic abnormalities. *Invest Radiol* 9:479, 1974)

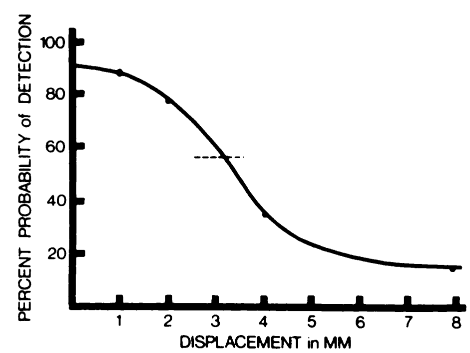

FIG. 3.—Probability of detecting nodule on subtraction film plotted against displacement (improper registration) of film containing nodule and film without nodule. Dashed line = average probability of detection for unsubtracted displays.

To improve detection of early lung lesions, particularly small cancers, ideally one would like to subtract films taken at some longer interval such as 6–12 months. The problem of image registration then becomes a major limiting factor. Two approaches are being studied: (1) positioning the patient in a reproducible way and (2) using computer programs to stretch or move anatomic structures on one film in order to achieve registration with the other [5].

To determine how close registration has to be to improve detection, the following experiment was done. A series of nodules ranging in size from 0.5 to 3 cm in diameter were artificially superimposed on 25 normal chest films at various locations in the lungs using a photographic technique [6] and

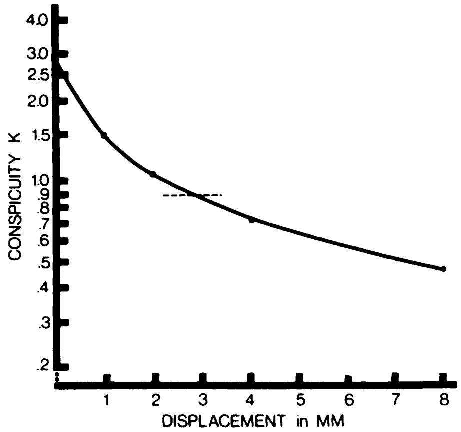

FIG. 4.—Effect of displacement of two subtracted radiographs on conspicuity of nodular lesion. Dashed line = average conspicuity for unsubtracted displays.

Kodak RP-D film. A reversal film was produced for each normal film on Kodak RP-SU film. The nodule films were then superimposed on the normal reversal films with horizontal displacements of 0, 1, 2, 4, and 8 mm. They were photographed on 35 mm slides, taking great care to maintain density ranges and contrasts during copying. This resulted in a series of 300 slides, half normal and half with nodules, in six modes of display: unsubtracted, perfect subtraction, and 1, 2, 3, 4, and 8 mm of displacement. These slides were projected on a rear view screen to standard 14×17 inch size and displayed in random order to five film readers. Each film reader was shown the series two times so that each nodule film was seen 10 times. The probability of detection of the nodule was then calculated.

Figure 3 shows the probability of detection of the subtracted films plotted against displacement. The average probability of detection of the unsubtracted films is also shown. With lesions in the 5–30 mm range, detection is improved by subtraction as long as registration error is limited to less than 3 mm. Otherwise detection is worse.

As a further check of the conspicuity hypothesis, K was measured for each of the nodules on both subtracted and unsubtracted films. Figure 4 shows the conspicuity plotted against displacement in millimeters on a semilogarithmic scale compared to the average conspicuity value for unsubtracted films. Again the crossover value is at about 3 mm.

Practical Application

After establishing a theoretical limit for registration, an attempt was made to realize that limit in practice. A simple device to position a patient in the erect position in front of a film cassette was constructed of aluminum tubing. Shown in figure 5, it consists of a chin rest on the top of the cassette and two cradles acting like crutches with an extended support running from the axilla to the elbow to hold the arms in a horizontal position. A volunteer was radiographed and returned 1 week later for a second frontal chest film. This time three plastic nodules 1 cm in diameter were attached to the skin of his back so that they would superimpose on the lungs. Figure 6 shows the "nodule film" and the result of subtracting the original film from that

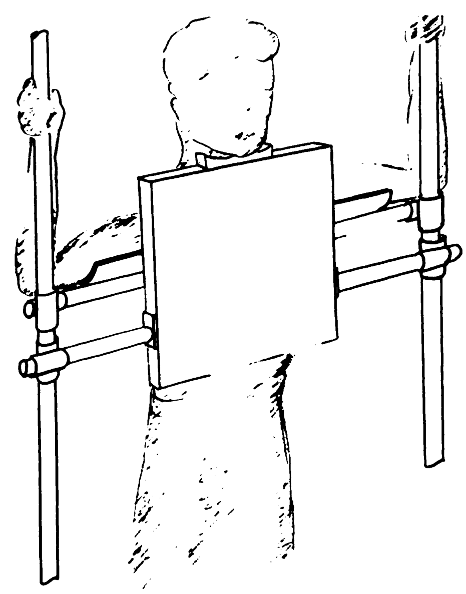

FIG. 5.—Simple device used to position patient. Patient is restrained by chin rest atop screen/film cassette, arm supports, and hand grip. Pictures are taken at full inhalation.

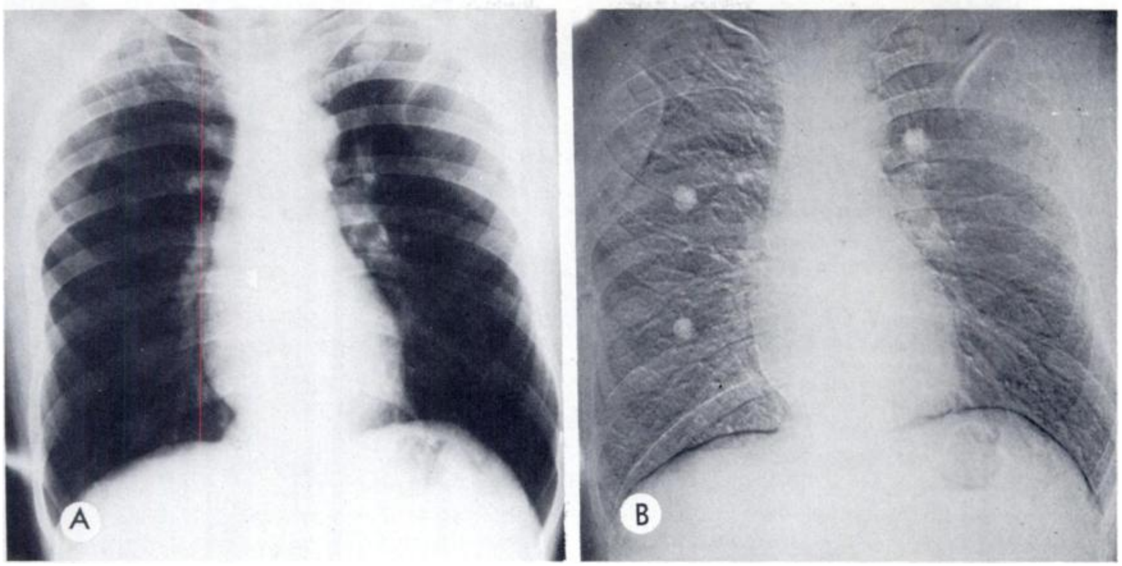

FIG. 6.—*A*, Film of person with three plastic nodules taped to back. *B*, Result of subtracting normal chest film of same person obtained at different time.

taken a week later. Clearly the visibility of the nodules has improved. Conspicuity was measured for each nodule in the subtracted and unsubtracted image (table I). The K value has increased, and since it has been shown that the probability of detection increases with increased conspicuity, it follows that subtraction *can* work for the chest under clinical conditions.

DISCUSSION AND CONCLUSIONS

The fact that a technique works is a necessary demonstration but is not sufficient to even begin a clinical study. A highly motivated group of volunteers who understand exactly what to do is not representative of any patient population. Much

TABLE I

CONSPICUITY VALUES OF SIMULATED NODULES FOR UNSUBTRACTED AND SUBTRACTED FILMS

Location	Original Film	Subtracted Film
Right lobe:		
Middle	1.43	2.18
Upper	1.91	2.58
Left upper lobe	1.17	2.66

more effort needs to be directed to the positioning device, particularly with respect to controlling the level of the hemidiaphragms at the time of exposure. Electronic devices using an image intensifier have been suggested but not tested [5].

We believe that the most important aspect of this work is the development of a rational mathematical basis for describing radiographic observational error. A process that is not understood is difficult to improve by any means but serendipity. The concept of conspicuity has been used to describe the effect of both random noise [7] and structural noise [8] on the detection of targets by peripheral vision and may be of value in the description of the effect of the visual search process on detection [9]. At present the mathematical formulation is only valid for circumscribed lesions where the border can be either definitely identified or extrapolated with a high level of confidence. Generalization of the concept to other abnormalities is essential. Nevertheless, it does provide a firm rationale for further subtraction studies and may provide an analytical technique for evaluating the potential usefulness of various patient

positioning apparatuses without resorting to subjective appraisals or clinical trials which should be reserved for techniques where the expectation of success is high.

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