A Simple Filtering Routine for Radionuclide Bone Images

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The evaluation is carried out of a simple filtering routine for improving the detectability of low contrast lesions in bone scans. With this routine, the unprocessed image is displayed together with three filtered versions, the final decision on the presence of abnormalities being made by comparing the four images. Emphasis is placed on producing a routine which is quick in implementation and, therefore, only small filter arrays are used. Using a routine consisting of a low-pass, a median, and a differential filter, 73% more lesions are detected when the filtered images are also used. The whole routine takes less than 1 min to run.

J Nucl Med 26:1081–1084, 1985

While much effort has been put into the development of filters for radionuclide images, there is still less than widespread acceptance of their value for improving the detectability of focal abnormalities. Pitt and Sharp (*1*) have shown that lesions in bone scans which can be detected by a simple quantitative technique are, in practice, missed because the observer cannot see them. Image filtering may provide a way of overcoming this problem.

Filtering "distorts" the original image, often introducing artifacts which may be mistaken for lesions. It is, therefore, important that the original image be displayed together with the filtered version. Also, processing need not be confined to just one filter, the final decision on the presence of lesions being made by comparing the different versions of the same image (*2*).

If such a scheme is to be used routinely, then the chosen filter routines must be fast so that the complete group of images is produced in, perhaps, less than 2 min.

This paper investigates whether such a simple filtering scheme can improve the detectability of lesions in bone scans. The bone scans were presented on a 128 × 128 array and all filtering routines were carried out on a PDP 11/40 computer.

Received Dec. 20, 1984; revision accepted Apr. 17, 1985.

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MATERIALS AND METHOD

Choice of filter

The most frequently used noise reduction filter, the so called nine-point filter (*3*), is fast, taking less than 1 sec for a 128 x 128 image, but in these bone images it was found to produce an unacceptably large number of artifacts. Instead, a low-pass filter was chosen, the basic rectangular shape of the filter in frequency spaced being modified by a Hamming window function (*4*). A cutoff frequency of 1.3 cm^{-1} was chosen to give what was judged visually to be an acceptable degree of smoothing. Filtering was carried out by convolution, the filter function being transformed into the object domain.

The number of terms or coefficients in the filter effects both its speed and the type of artifact produced. For this low-pass filter at least three terms, i.e., a center term plus three terms on each side, were found to be necessary. An "asterisk" form of filter was used, consisting of filter coefficients in the horizontal, vertical, and the two 45° diagonals only. To shorten processing time, the values of the filter coefficients used for the horizontal and vertical terms were also used for the diagonals. The filter took 10 sec for a 128 × 128 image, its effect being shown in Fig. 1b. Figure 1a shows the same data prior to filtering.

The disadvantage of using this type of filter is that it blurs the image by averaging across edges. In contrast, the median filter (*5*) removes noise spikes yet retains edges and ramps. The version of the filter chosen for this study had a center term plus one term on each side in the horizontal and vertical directions. This cross-shaped form preserves horizontal and vertical lines. The processing time was 5 sec, Fig. 1c showing the bone image after median filtering.

A differential filter (*6*) whose frequency response "rolled

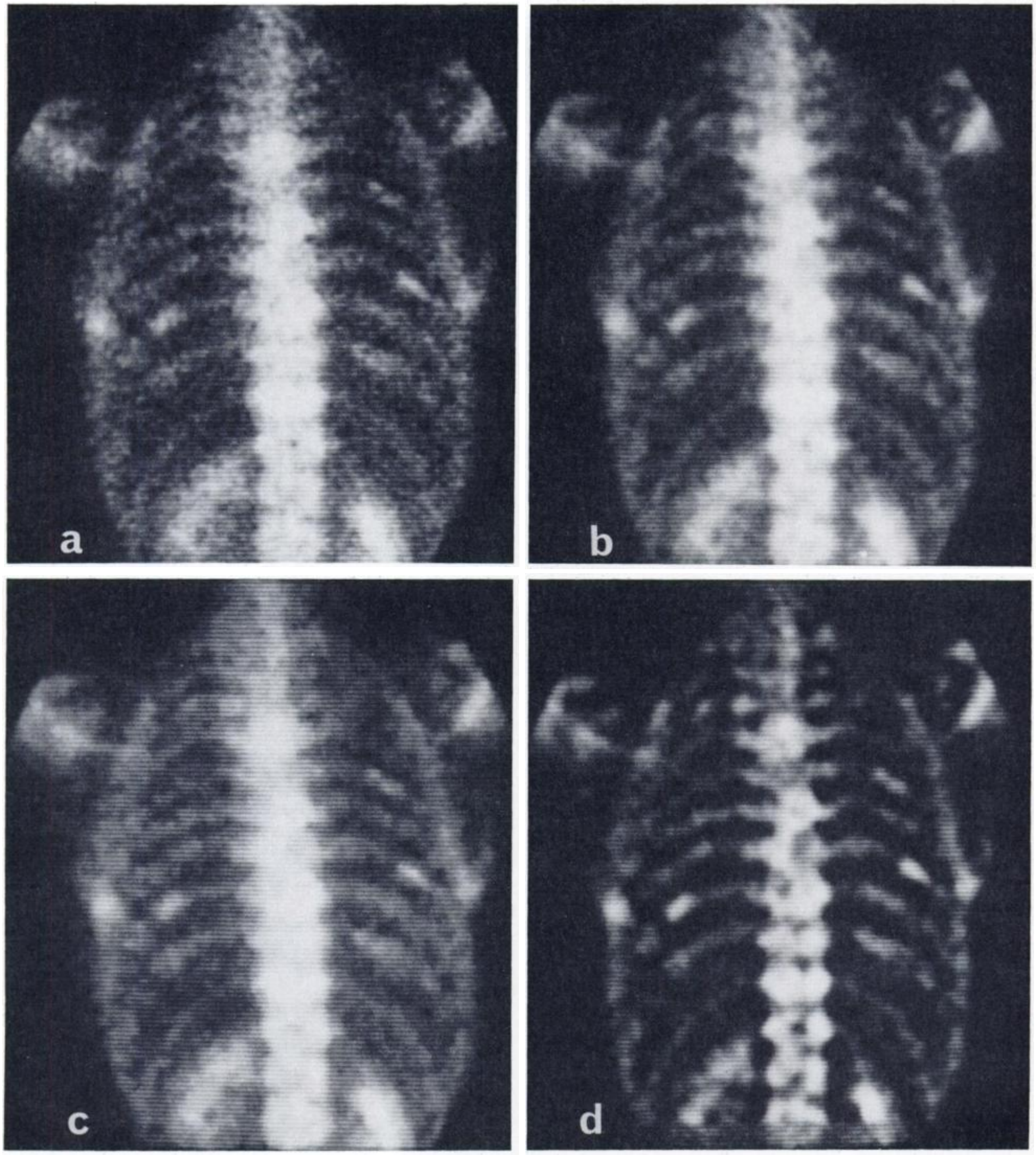

FIGURE 1
Set of filtered plus unfiltered images. There is total of ten abnormalities in this image. (a) Original image; (b) Low-pass filtered image; (c) Median filtered image; (d) Differential filtered image

off" at 0.6 cm^{-1} was used as the third and final filter. This enhances those areas of the image in which the count density is changing rapidly, Fig. 1d. A three-term asterisk filter was used, processing time being 18 sec. Filtering was again by convolution in object space.

Evaluation

Computer simulated abnormalities were added to ten upper posterior view bone scans (*7*); these images had been reported as normal and the patients had not shown clinical signs of metastatic disease during the subsequent 2-yr follow-up period. Between seven and 12 lesions were added to each image.

The images, digitized onto a 128 × 128 matrix, were color coded according to the heated body spectrum with 255 intensity levels and displayed on a TV monitor interfaced to a DEC

TABLE 1
Total Number of Abnormalities*

Viewer	Number of times that an abnormality was seen: Only in the unfiltered image presensation	In the filtered + unfiltered images but not the unfiltered image on its own	In both the unfiltered image and in the filtered + unfiltered images	In neither presentation
A	6	27	29	29
B	2	32	31	26
C	0	27	35	29
D	4	31	28	28
E	3	25	32	21
F	6	29	29	27

* As same images are used in both experiments, i.e., when only unfiltered version of image is displayed and when quadrant presentation of unfiltered plus filtered images is shown, then particular abnormality may be seen only in first experiment, only in quadrant presentation, in both experiments or may not be seen at all.

Vax 11/750 computer by way of a Sigmex 7000 series advanced image display system. Six observers, five of whom were clinically experienced in reporting bone scans, looked at the images. Viewing distance and image brightness were under the control of the observer.

Each observer was shown two sets of images; the first consisted of the ten unprocessed images, each displayed on its own, and the second the unprocessed image together with the three filtered versions. The sequence of presentation was randomized. Observers were asked to report only the obvious abnormalities, the location of a possible lesion being indicated by an operator controlled cursor. No limit was placed on the number of possible abnormalities which could be reported in an image.

RESULTS

Each response can be classified as either a correct or incorrect identification of an abnormality, i.e., true-or false-positive response, respectively. These are shown in Tables 1 and 2 for the two presentations.

The effect of introducing filtered images was tested by comparing the number of abnormalities correctly identified only on the unfiltered image with the number seen only on the unfiltered plus filtered images, i.e., columns 2 and 3 of Table 1. Since the same images were used in both presentations, McNemar's test (*8*) provides a suitable test for the statistical significance of the difference. All six observers detected significantly more abnormalities when the filtered images were used ($p>0.95$).

Such an increase in the number of true-positive responses may be of little value if the number of false positives, i.e., artifacts mistakenly reported as abnormalities, also increases. Table 2 shows that there was no increase in the number of false positives when the filtered images were introduced.

CONCLUSIONS AND DISCUSSION

The simple scheme of image processing significantly improved the detectability of lesions in bones scans; on average, the number of lesions correctly detected increased by 73% after filtering. No attempt was made in this study to investigate all possible types of filters and further work is in progress. The criterion used was that processing time should be short with the number of terms in the filter array being kept to a minimum, subject to the need to avoid introducing artifacts into the filtered image. For this reason only stationary filters were considered. As the total processing time, using the type of computer commonly found in nuclear medicine processing systems, was less than 1 min it is considered that the study has shown the feasibility of this approach to image filtering.

Signal detection theory has been used by several workers to measure the efficacy of image processing (*2,9–15*). When, as in our case, there is no restriction on the number of locations at which the lesion may occur, it is not possible to express the number of false-positive responses as a percentage and so conventional receiver operating characteristic (ROC) curves cannot be used. The free response operating characteristic (FROC) curve proposed by Brunch (*16*) may offer a solution to this problem. Instead we chose to keep the observers' decision criterion fixed. Since it was observed that the number of false-positive responses did not increase when the filtered images were introduced, the effect of

TABLE 2
Total Number of False-Positive Responses, i.e., Artifacts Incorrectly Identified as Abnormalities, Reported in Two Experiments

Viewer	Number of false positives: Unfiltered images	Filtered + unfiltered images
A	35	22
B	23	20
C	35	13
D	34	24
E	35	18
F	32	16

filtering can be measured simply by comparing true-positive response rates.

The choice of presenting three filtered images together with the unprocessed one was made solely for convenience of display, although it is obviously undesirable to have a large number of filtered images displayed concurrently. One possibility might be to have a range of simple filters available, the operator choosing the ones most suitable for the imaging problem under consideration. There still needs to be considerable work done on investigating the suitability of various filters.

ACKNOWLEDGMENTS

The authors are grateful to Dr. R. Pitt for the bone images and the program to add lesions to them. The authors are also grateful to Professor J. R. Mallard for his encouragement. At the time this work was carried out, one of the authors (PGBR) was supported by a grant from the Science and Engineering Research Council.

REFERENCES

1. Pitt WR, Sharp PF: Comparison of quantitative and visual detection of new focal bone lesions. *J Nucl Med*: 26:230-236, 1985
2. Houston AS, Sharp PF, Tofts PS, et al: A multicentre comparison of computer assisted image processing and display methods in scintigraphy. *Phys Med Biol* 24: 547-558, 1979
3. Miller TR, Sampathkumaran KS: Digital filtering in nuclear medicine. *J Nucl Med* 23:66-72, 1982
4. Ackroyd MH: *Digital Filters*, London, Butterworth, 1973, p 49
5. Rosenfeld A, Kak A: *Digital Picture Processing Vol 1*, London, Academic Press, 1982, pp 261-263
6. Sharp PF: The presentation of photon-limited images. In *Technical Advances in Biomedical Physics*, Dendy PP, Ernst DW, Şengün A, eds. The Hague, Martinus Nijhoff, 1984, pp 235-258
7. Pitt WR, Sharp PF, Chesser RB, et al: Radionuclide image minification can compensate for coarse digitization. *J Nucl Med* 24:1046-1054, 1983
8. Armitage P: *Statistical Methods in Medical Research*, Oxford, Blackwell, 1977, p 127
9. Kuhl DE, Sanders TD, Edwards O, et al: Failure to improve observer performance with scan smoothing. *J Nucl Med* 13:752-757, 1972
10. IAEA: Co-ordinated research programme on the intercomparison of computer assisted scintigraphic techniques. Progress report. In *Medical Radioisotope Scintigraphy Vol. 1*, Vienna, IAEA, 1973, pp 727-744
11. IAEA: Co-ordinated research programme on the intercomparison of computer assisted scintigraphic techniques. Second progress report. In *Medical Radionuclide Imaging Vol. 1*, Vienna, IAEA, 1977, pp 571-584
12. IAEA: Co-ordinated research programme on the intercomparison of computer assisted scintigraphic techniques. Third progress report. In *Medical Radionuclide Imaging Vol. 1*, Vienna, IAEA, 1977, pp 585-616
13. Houston AS, Macleod MA: An intercomparison of computer assisted data processing and display methods in radioisotope scintigraphy using mathematical tumours. *Phys Med Biol* 22:1097-1114, 1977
14. Houston AS, Macleod MA: An intercomparison of computer assisted image processing and display methods in liver scintigraphy. *Phys Med Biol* 24:559-570, 1979
15. King MA, Doherty PW, Schwinger RB, et al: Fast count-dependent digital filtering of nuclear medicine images. *J Nucl Med* 24:1039-1045, 1983
16. Brunch PC, Hamilton JF, Sanderson GK, et al: A free response approach to the measurement and characterisation of radiographic observer performance. *SPIE Optical Instrumentation in Medicine VI Vol 127*, 124-135, 1977