

Digital Data Processing of Images

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SUMMARY

Digital data processing was investigated to perform image processing. Image smoothing and restoration were explored and promising results obtained. The use of the computer, not only as a data management device, but as an important tool to render quantitative information, was illustrated by lung function determination.

The availability of on-line computers for image processing represents a major advance in the radiological investigation of organ function.

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Image evaluation and processing by computer is an increasingly important aspect of radiology.^{1,2} The fundamental methods for X-ray and scintigraphic image processing are the same, but as scintigraphic image data lend themselves to computer storage, this article will only be concerned with the image enhancement of scintigrams.

Two applications of image processing are described. In an attempt to compensate for the poor resolution obtained from scintigraphic equipment, image enhancement by computer was investigated. The use of the digital computer to quantitate organ function after dynamic studies using the gamma camera will also be described and quantitation of lung function investigations used as an example.

IMAGE ENHANCEMENT

The purpose of image enhancement is to process the image in such a way that more information is available for extraction by the human visual system. Image enhancement therefore increases the probability of target detection, but relies on the brain and not on the computer for pattern recognition. The poor resolution of scintigrams is caused mainly by the low photon yield obtained from radio-isotopes. If, therefore, a very high spatial resolution is used, the observed count rate is so low that one cannot

distinguish between statistical fluctuations in count rate and changes caused by radio-isotope distribution. An optimum resolution-sensitivity relation does exist and this can be optimised by means of the computer.

The spatial resolution and sensitivity relation of imaging devices can be well illustrated if the performance of scintigraphic instruments is expressed in the spatial frequency domain. In the spatial frequency domain the performance of an instrument is described by the extent to which the instrument reproduces a sinusoidal object pattern. If one therefore constructs phantoms which sinusoidal isotope distributions of different frequencies, it will be found that at low frequencies these patterns can be well reproduced, but as the frequency increases the reproduced amplitudes are reduced (Fig. 1). The ratio of the observed amplitude and the isotope distribution is called the modulation transfer function (Fig. 2). The modulation transfer function is accepted in radiology as the most accurate method of expressing image resolution. The modulation transfer function of a scintigraphic instrument will be determined by the spatial resolution of the collimator detector. During the measurement of the isotope distribution, however, high frequency noise is introduced as a result of the statistical fluctuations in the count rate. At high count rates the noise component is small, but at low count rates the relative noise component increases, to decrease the over-all image information content.

How can image enhancement be performed? It is clear from the data in the frequency domain that if the noise component of the observed scintigrams is removed, enhancement will be produced. The noise component can be assumed to be those frequencies higher than the frequency where the noise component equals the target component. This process of removal of high frequency noise is called smoothing.

Having enhanced the image by removing statistical fluctuations, the image will still be degraded as a result of limited resolution of the detector as demonstrated by the modulation transfer function. To correct spatial resolution of the collimator one can use the inverse of the modulation transfer function (Fig. 3). In other words, because the modulation transfer function expresses the fraction with which the real frequency component is reproduced, one can correct this component. By correcting all frequencies, image restoration can be performed.

Image restoration cannot be performed at high frequencies, because the noise present is also enhanced to produce meaningless information. The highest frequency, therefore, where restoration can be performed depends on the cut-off frequency, which depends on the count rate and the smoothing which was applied.

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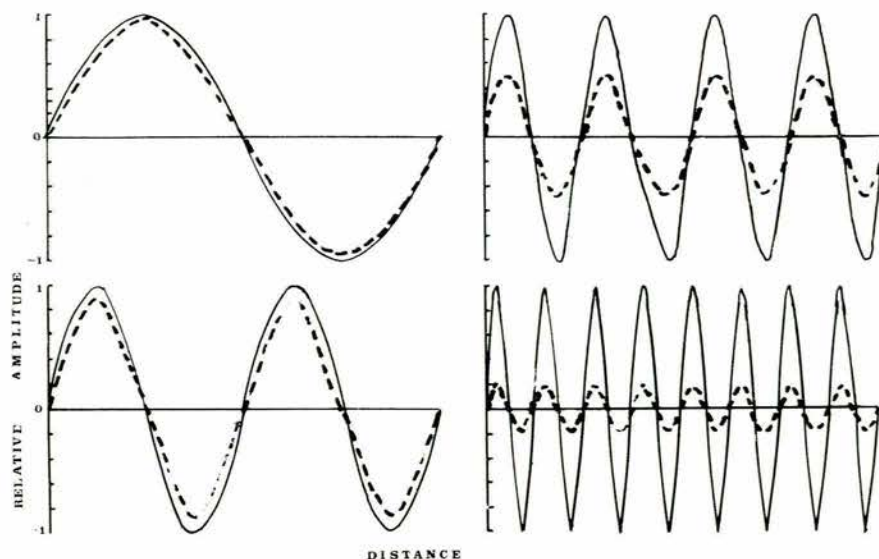


Fig. 1. The deterioration in the reproduction of the radio-isotope distribution. The radio-isotope distribution is represented by the solid line and the reproduction deterioration as the frequency increases is reproduced by the dotted lines.

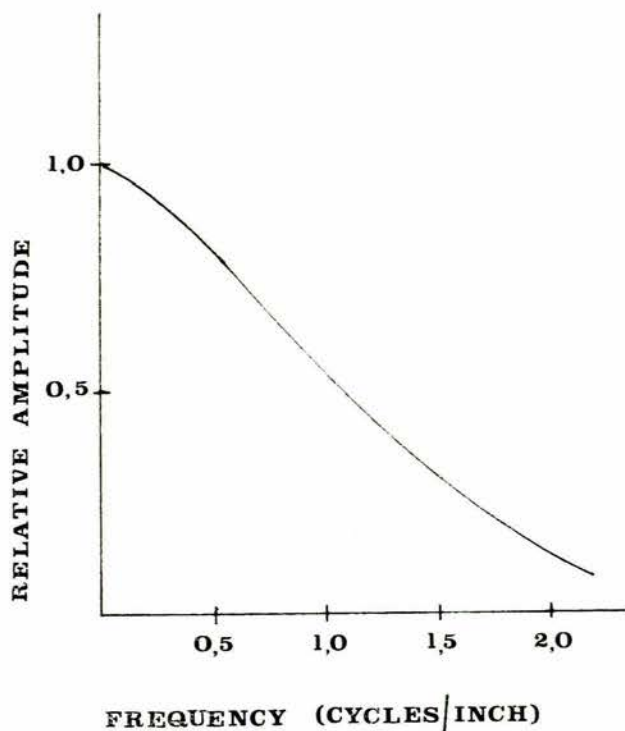


Fig. 2. The modulation transfer function of a typical image device.

RESULTS

In liver and kidney scintigrams and scans obtained with ⁶⁷Ga-citrate it was found that smoothing did contribute significantly to the information available to the observer.

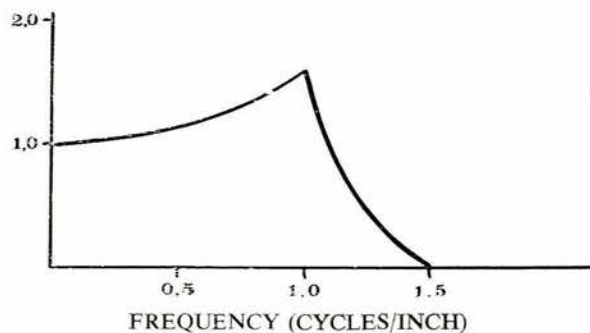


Fig. 3. The filter used to produce image restoration.

Smoothing is an important aspect of image enhancement, since it is easily performed by dedicated computers.

Fig. 4 illustrates the image enhancement obtained after the processing of scintigrams of poorly-functioning kidneys. Fig. 4 (top) illustrates the normal photoscan, while Fig. 4 (bottom) demonstrates the improved image after smoothing. Fig. 5 illustrates the improvement of image quality of a scan obtained with ⁶⁷Ga-citrate from a patient with a carcinoma of the bronchus.

Fig. 6 shows the effect of smoothing and restoration. This is a scan made of a patient with suspected liver secondaries. The first picture is without any processing, the second after smoothing, and the third with image restoration. After the patient died 3 months later, multiple secondaries were confirmed at postmortem examination.

Although we obtained significant improvement in image quality, better results with image restoration can be expected.^{3,4} With this object in view, we are at present writing computer programmes to simulate Siemens' Star

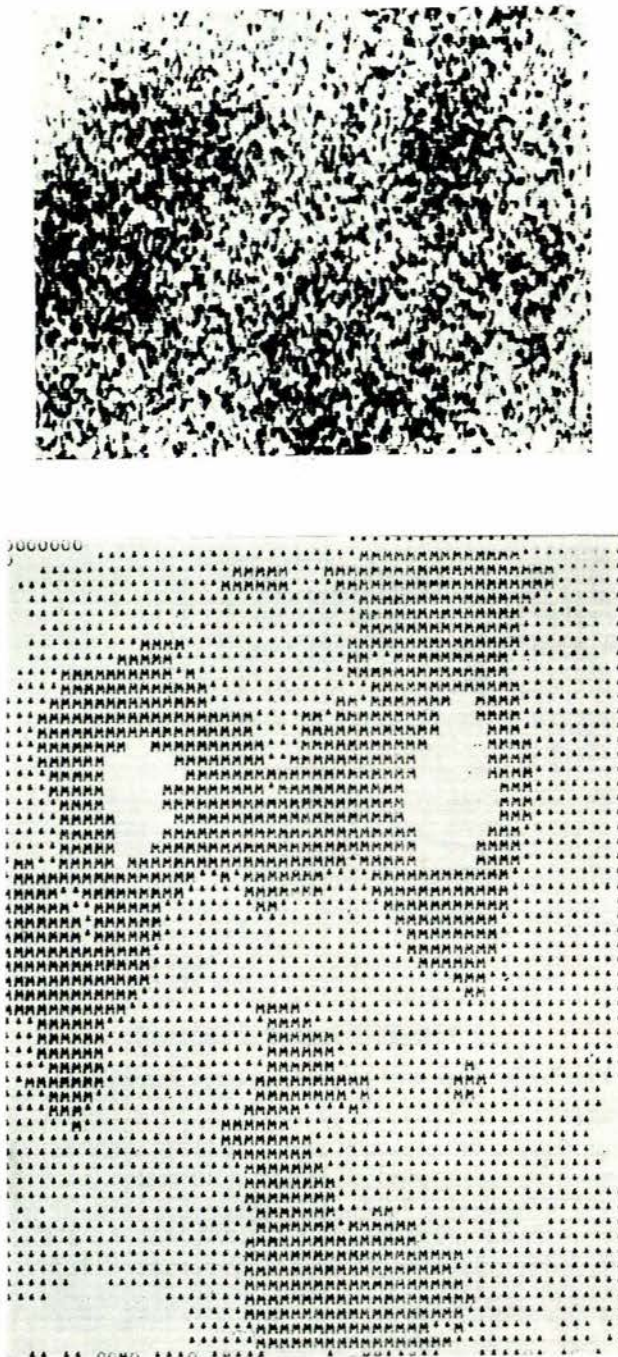


Fig. 4. Top: The photo-scintigram of poorly functioning kidneys. Bottom: This image represents the kidneys after image enhancement.

Patterns and other test patterns with statistical fluctuations to observe the effect of the different filters.

Work has been done only to improve image quality in terms of sensitivity and spatial resolution. Image enhancement can be extended to correct for gamma camera non-uniformity and linearity.

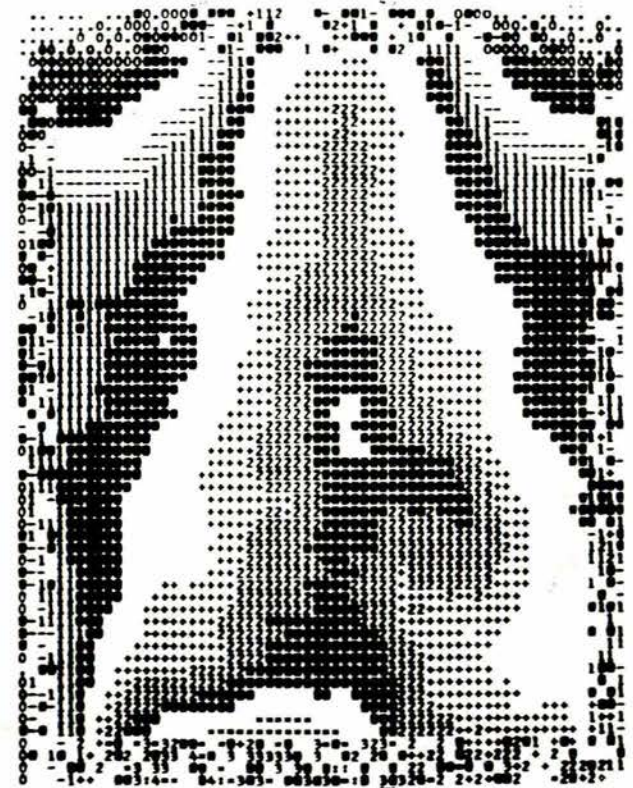
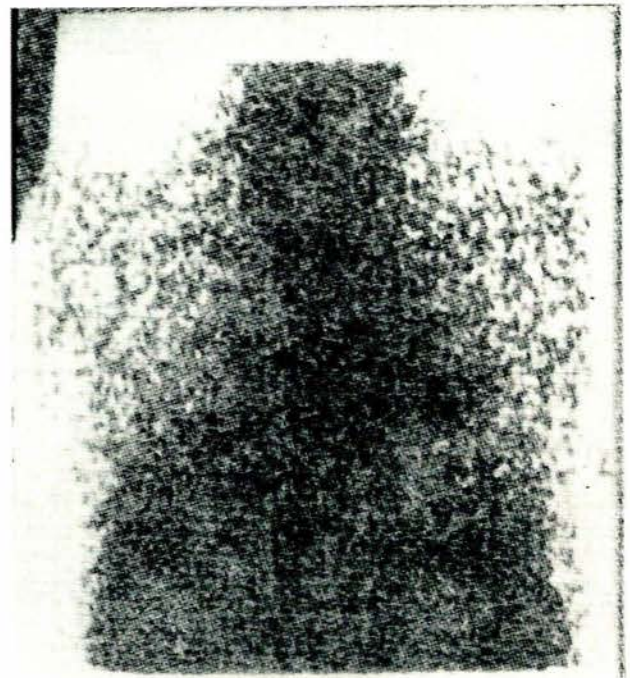


Fig. 5: Top: A photo-scintigram of a patient with cancer of the bronchus. Bottom: The significant improvement in image quality obtained after image enhancement.

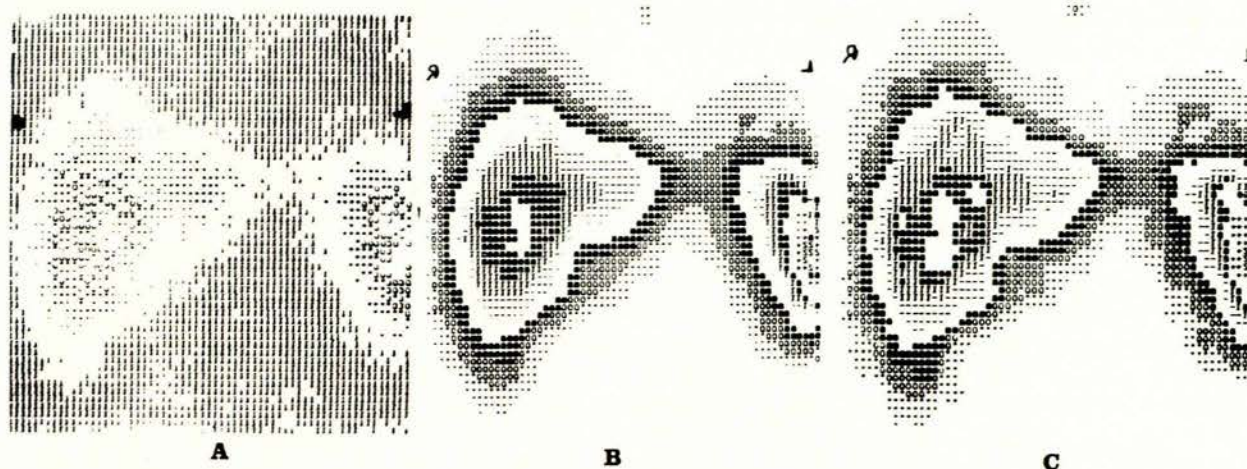


Fig. 6. A liver scan of a patient with suspected metastases; (A) is the scintigram without processing; (B) is the scintigram after smoothing; and (C) is the scintigram after restoration. Multiple small filling defects become visible only after restoration.

COMPUTER PROCESSING OF DYNAMIC STUDIES

Image enhancement is of interest in the visual interpretation of scintigrams. With the use of the gamma camera, dynamic studies can be obtained, the purpose of which is to achieve serial visual images to determine organ function and blood flow. Although organ function can be judged by visual interpretation of the scintigrams, more information can be obtained if function is quantitated. To analyse dynamic studies it is necessary to store the serial images.

The data can usually be replayed to obtain photographs or dynamic count-rate curves from any preselected region of interest. The count-rate curves can be analysed by on-line or off-line computers to determine quantitative organ function. Lung function determination will be described to illustrate the use of the computer as a data analysis system and not just as a data management device. The general availability of on-line computers to perform these tasks represents a major advance in the radiological investigations of the lungs, heart, brain and other organs.

METHOD

The Setting-up of Patients

The patient is seated upright with his back against the scintillation camera. The patient is positioned using a transmission image (Fig. 7) which is recorded for 20 seconds. The normal background is then recorded. The separate sections of the study consist of (a) ventilation; (b) perfusion; and (c) steady state or volume determination.⁵⁻⁷

Procedure to determine perfusion. When the storage of data has started, the patient is instructed to hold his breath at the end of a normal expiration (functional

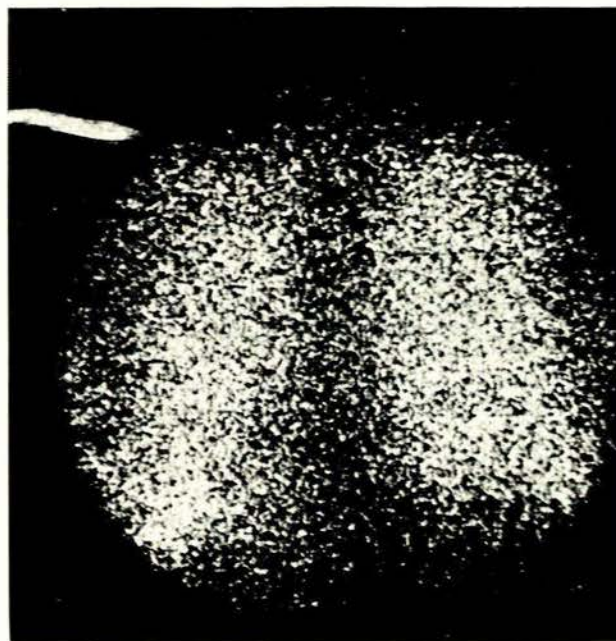


Fig. 7. Lung transmission scintigrams.

residual capacity). ¹³³Xe dissolved in saline is rapidly injected and the patient then inspires to total lung capacity and holds his breath for at least 20 seconds, and then exhales into the air until all the gas is cleared from the lungs.

Procedure to determine volume. While data are still recorded, rebreathing is started into a closed circuit spirometer until equilibrium is reached. The patient then holds his breath at total lung capacity to record regional lung volumes. This is followed by breath-holding at minimal lung capacity and then breathing at tidal volume into the air until the xenon is cleared from the lungs.

Procedure to determine ventilation. Ventilation is determined in a similar way to perfusion, after a single maximal inspiration of ^{133}Xe in oxygen.

Data Collection

Each lung is conveniently divided into three regions per determination. Using video-tape display, areas of interest are selected and the count rate during breath-holding is obtained from each region. The washout curves after breath-holding are also obtained.

The programme then calculates the relative distribution of the gas during ventilation, volume and perfusion studies. Washout data are computer-analysed by the following three methods: graphical logarithmic analysis according to a double exponential model; analysis by iteration to a single exponential model; and analysis by iteration to a double exponential model.

A facility for calculation of the distribution of transmission scintigrams and perfusion studies with microspheres is also allowed for. The indices of ventilation are then calculated as the relative ventilation per relative regional volume. Perfusion and the ventilation perfusion ratio and the ventilation rates from the ventilation washout curves are also calculated.

Lung Function

The facility to determine regional lung function is a major advance in the radiology of lung function investigations. However, since six regions are selected, the playback of these regional data is time-consuming and an on-line computer is necessary for the automatic analysis of data. The facility to view the dynamic process not only ensures optimal selection of regions of interest, but

serves to detect other factors which may influence the investigation, such as a poor injection or delayed filling of the lungs due to a cardiac abnormality.

During the static study determination of ventilation, perfusion and ventilation perfusion ratio indices, images of these indices can be achieved by the computer as one image can be divided by another.⁵ These ratio techniques have been used by us with success for experimental heart investigations where multiple isotopes were used^{2,6,7} and also during the investigation of ^{125}I (Fig. 8). These techniques of displaying functional indices as an image can be extended to display rate constants of washout curves and initial count rates after analysis.

CONCLUSION

Our purpose was to demonstrate some aspects of digital data processing. Since a large volume of data is generated by dynamic studies, a computer is necessary for data retrieval and analysis.

Dynamic studies are not limited to the lung, but are applied in the determination of blood flow in organs such as the brain, determination of kidney function and the diagnosis of cardiac abnormalities.

Image enhancement is important during static scintigraphy to improve clinical accuracy of diagnosis. These techniques of image processing can also be extended to the analysis of count-rate curves, and these methods would be particularly valuable in the demonstration of cardiac shunts during paediatric investigations.³

Image enhancement is not limited to scintigraphy but applied to radiology. Computer data analysis of X-ray films will not only improve image quality but if stored in a computer can save a great deal of time in retrieving films and will also facilitate programmed reporting.

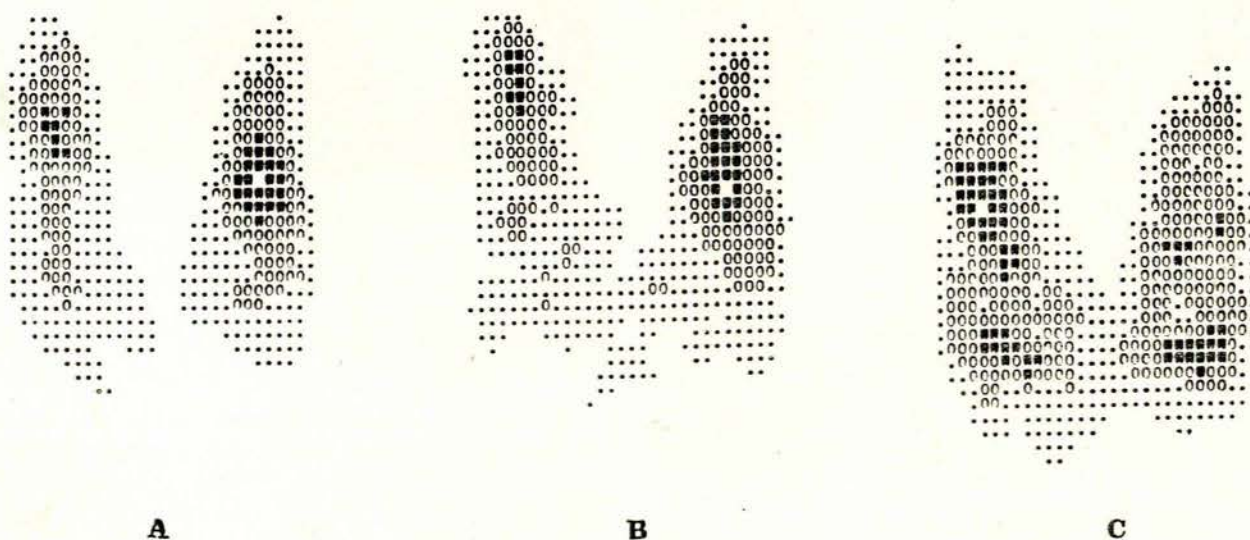


Fig. 8. Thyroid scintigram with ^{125}I (A) is the enhanced scintigram obtained with 150 KeV and (B) is the scintigrams obtained with 28 KeV photon energy. (C) is the ratio scan of (A) and (B) and demonstrates a nodular thyroid.

In conclusion, scintigraphic data lend themselves to computer analysis for more accurate results in patient care.

REFERENCES

1. Kruger, R. P., Hall, E. J., Dwyer, S. J. and Lodwick, G. S. (1971): *Biomedical Computing*, **2**, 215.
2. Lötter, M. G. (1971): "n Ondersoek na digitale dataverwerking by flikkergrafie," p. 53, Ph.D. thesis, University of Stellenbosch.
3. Kirch, D. L., Brown, D. W. and Stern, D. M. (1972): *J. Nucl. Med.*, **13**, 440.
4. Gooden, D. S., Farmer, C. H. and Kauth, J. E. (1972): *J. Okla Med. Assoc.*, **65**, 3.
5. Burdine, J. A., Veerasamy Alagarsamy, Ryder, L. A. and Care, W. N. (1972): *J. Nucl. Med.*, **45**, 418.
6. De Wet Lubbe, J. J., Barnard, P. M., White, J. J. and Lötter, M. G. (1971): *S. Afr. Med. J.*, **45**, 280.
7. White, J. J., De Wet Lubbe, J. J., Lunders, E., Andrews, H. G., Lötter, M. G. and Barnard, P. M. (1971): *Current Topics in Surgical Research*, p. 285. New York: Academic Press.
8. Lötter, M. G., Van der Merwe, E. J., Van Heerden, P. D. R. and Le Roux, P. L. M. (1971): *S. Afr. Med. J.*, **45**, 186.