The use of computers in nuclear medicine

By L. Csernay

The development of the isotope technique during the past ten to fifteen years has increased our diagnostic possibilities in many fields. Answers are obtained to completely new, previously unapproachable questions, and today the results of the older, more classical procedures can be attained more rapidly, more accurately, and with less inconvenience to the patient.

One of the large groups of routine isotope procedures is comprised of the morphological examination methods.

Liver scintigraphy is most frequently performed; in our laboratory alone there are more than 350 such examinations annually. Scintigraphic projection of the liver can be carried out with either a moving or a stationary detector (with a gamma camera) after the intravenous injection of radiogold, ^{99m}Tc or a ^{113m}In colloid preparation. Using a gamma camera we can also work with labelled Bengal red, which has rapid selection.

Electronic data processing in scintigraphic examinations provides not only quantitative, but also qualitative benefits. For us to be able to understand the refinements of the computer technique, it is first necessary to consider the theoretical and practical problems of the evaluation of scintigraphic examinations and the scintigrams produced.

What are the data which we wish to learn about the examined organ, for instance the liver, when we carry out a scintigraphic examination? The aim is to determine the size of the liver, its form, its position, and the uniformity or non-uniformity of the distribution of the activity. Our other task is to identify in the substance of the liver those circumscribed regions and nodules which differ from the hepatic tissue in their isotope concentration effects; they may enhance, but they usually decrease the normal concentration of the labelled active preparations used in the examination. It is decisive in the identification of regions behaving differently as regards isotope enrichment (tumours, cysts, abscesses), if the occurrence of such areas in the liver can be excluded by the examination with certainty in the case of suspicion.

The first part of the complex task is the simpler. The diagnosis of space-reducing processes in the substance of the liver is appreciably more difficult. Recognition of fist-sized tumours or cysts, or a completely uniform isotope distribution is relatively easy on technically adequate photographs. In perhaps one third of the examinations the opinion of the diagnosing physician may be questionable. In these cases it is usually a matter of smaller nodules, 2—4 cm in diameter, or it may be that the non-uniformity of the isotope enrichment and the anatomical situation lead to the incorrect suggestion of a diagnosis of minor nodules. The expectations from scintigraphy are fulfilled if it provides suitably reliable accuracy in the questionable cases, in the diagnosis or exclusion of minor lesions. The minimum size of the cold region which can be detected in the ideal case is determined by the physical parameters of the instrument. The detection of nodules larger than this is possible in principle, but in practice remains uncertain up to a much larger limit, above which the diagnosis is no longer problematic. The aim of the examinations is to diagnose the theoretically identifiable nodules *in practice* too.

What are the factors which present obstacles to the attainment of this?

The statistical, non-uniform nature of the radiation, the distortion due to the collimator used, and the limitations of the resolution of the display system are all objective factors. The subjective evaluation of an obtained scintigram, however, means a further loss of information, or may even provide faulty information. The formulation of the findings influences their interpretation. It is not difficult to see that given acquired information can be interpreted in different ways by the clinician, merely because of the subjectivity of the formulation of the report. The potential of liver scintigraphy is deteriorated by the listed problems in just those cases where the lesions are small, and where a definite attitude affects the development of the future of the patient decisively. Electronic data processing can be used to combat all of the negative factors listed here.

The statistical nature of radioactive radiation is a physical regularity; its effect can not be eliminated, but can be substantially moderated by means of mathematical smoothing procedures.

On the application of a smoothing procedure, the statistical fluctuation regularly appearing on the scintigraphic picture is clearly reduced, the picture becomes more homogeneous, and the evaluability is improved. Attention must be drawn, however, to the fact that to a certain extent the smoothing procedures deteriorate the detection of areas differing in activities from those of their environments. (e.g. cold nodules), since the decreased activity values at the circumscribed position are changed in the direction of the higher level of the environment, and are smoothed. This undesirable effect occurs particularly on the use of a smoothing configuration with low centre-point weight, taking into account many adjacent elements. In spite of this, the use of smoothing procedures with appropriate discrimination has led to a significant advance in the evaluation of scintigrams. It is virtually inconceivable to carry out the method manually, since the processing of each scintigram would last 8—10 hours. For a medium-size computer the task, together with the new picture formation, requires 4—5 seconds machine time. The now basic step of electronic data processing of scintigrams is the smoothing of the data.

The second important problem of the scintigraphic procedure is that even the relatively most perfect, multichannel, focussed collimators are able to project the examined organ only with distortion.

If the two regions of different activities and also the activity-free detail between them, are projected by scintigraph, a picture differing from reality, or from the object-function, the distorted picture-function is obtained, which indicates activity even in the really activity-free regions, because the detector above these points also observes radiation from the active regions on the two sides. Projection of the picture-function and object-function onto each other, confirms that the obtained information differs from reality. The distorting effect of the side scatter can not be neglected in the examination of the liver, particularly in the case of the smaller nodules, their identification is significantly affected, and hence the diagnostic potential of the procedure is deteriorated.

The common aim of the focussing procedures used in electronic data processing is that the distorting effect of the collimator be reduced on the picture, and if possible eliminated. Various mathematical procedures can be employed, but they have in common that they take into account the extent of distortion of the collimator actually used in the examinations, and its viewing to the side. The iteration procedure, the residual tabular procedure, and the Norbert Wiener filter, operating with concrete physical values of the collimators, approximate the distorted picture-function to the real object-function. Among others, the difference is for example that the iteration procedure, repeated one after the other, improves the picture-function stepwise, while the residual tabular method and the Wiener filter, or inverse filter, approximate in one step. At any event, the use of the any of the focussing procedures results in a substantially improved picture, which is much closer to the projected object. The improvement of the picture permits the identification of smaller nodules in daily practice, while more realistic and certain decisions can be reached using the data of a given photograph. The focussing procedures and other mathematical methods can naturally not change the size of nodule theoretically detectable with a given collimator, nor do they allow the obtaining of information for which the detector-collimator system performing the charting is incapable. The size of nodule identifiable in practice is approximated to the theoretical value, and the distorted information is improved.

The different focussing procedures are generally carried out after one of the smoothing procedures discussed earlier, because the focussing methods are very sensitive to statistical fluctuations. In direct daily practice, the concrete question arises of what type of focussing procedure is worth using in the processing of liver scintigrams. The answer is decided by the consideration of two factors. For practice, the most optimum procedure is that which results in the greatest improvement, while at the same time the machine time devoted to the data processing is the least. Clearly we are forced to compromise, taking into account that computer time is fairly expensive all over the world. Naturally, if a private computer is available for use, this latter factor affects the choice to a lesser extent.

The third problem of the scintigraphic method is the restricted resolution of the recording system. The recording on the customary industrial scintigraphs is performed in general with a line-striking or number indicating system and with a photo-technique. It would be optimum in theory if the recording system were to resolve the difference between the most active and the radiation-free regions into as many sections as possible, and, taking 1 % recording divisions, were to divide the data mass into 100 values for example. In this case the small changes too would be identifiable. In practice, however, it is almost inconceivable that a picture consisting of 2000—4000 elemental points would be easy to survey and evaluate after being divided into 100 parts. The classification of the values into fewer classes clearly deteriorates the resolution. The recording system of the commercial scintigraphs exhibits a compromise solution; information is lost by the use of fewer value divisions, but at the same time diagnosis is made simpler by the increase of the clarity. The recording system of the scintigraph and the number of divisions can not be changed from case to case, and so only one or two concrete possibilities can be employed in the evaluation.

Here too electronic data processing results in an improvement in quality. With the use of 1—2 seconds machine time the data mass of the scintigraphic picture can be classified into very many different resolution groups; apart from one or two-digit numbers, various types of lettering, positive signs and empty spaces can be used for

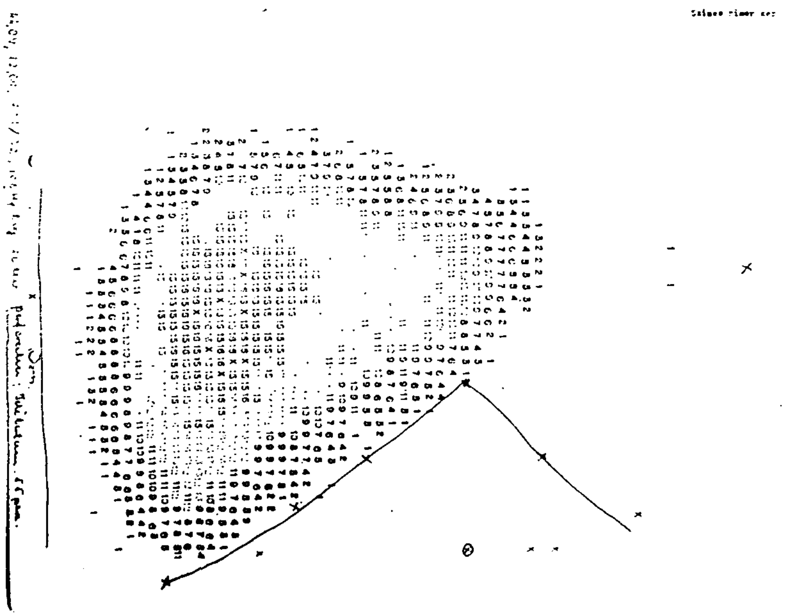

Fig. 1
Original picture—normal liver scan

the recording; isointensity lines can be calculated, and these can be displayed in a coloured picture, on a television screen. Despite the large variety of display possibilities, the conflict between the number of divisions and the clarity can not be solved, but merely decreased. Accordingly, there is a need for a completely different solution. A classification into groups ensuring better resolution can be achieved in the given region by accentuating the data of a part-region which appears suspect on consideration of the original photograph. Thus, the number of divisions for this region will be greater than the corresponding number when the complete picture is divided up. If 20% is subtracted from the values of the accentuated part-region in each of four steps, one after another, and a new classification is carried out, keeping the number of divisions after each subtraction, the resolution is continually increased without a deterioration in the clarity of the picture.

In order to demonstrate what has been said, Fig. 1 shows the original picture and also recording types achieved by means of computer.

The number of divisions on the original picture prepared with the scintigraph is 16. The identification is made more difficult by a logarithmic relation between the size of the numbers and the activity values.

The picture prepared with a fast print-out provides more realistic information, with a similar number of divisions, but with a linear relation (see Fig. 2).

The calculation and plotting of the isointensity lines provides a satisfactory pictorial representation even with the use of fewer divisions, and the number of levels may be increased or decreased. Without a computer, level recording can not be solved, of course.

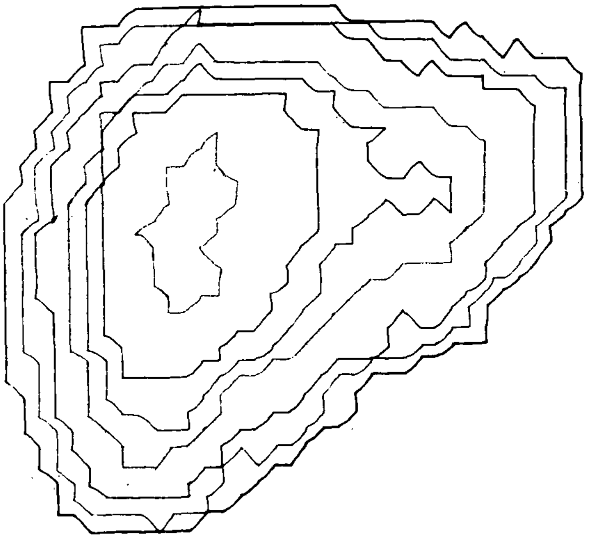

Fig. 2a
Isointensity lines picture—normal liver scan

The computer recording of the processed liver scintigram, of various forms and numbers of divisions, requires about 8—10 seconds per form. The analysis of problematic scintigrams with various recording forms needs 30—40 seconds, and finally, on the basis of the picture obtained with the most optimum recording as regards the task, an answer can be given to the question of the physician requesting the examination.

The fourth problem of the scintigraphic method is the subjective evaluation of the scintigrams. It can readily be seen that, depending on their specialist knowledge and their familiarity with the evaluation, different physicians may interpret a given scintigram in different ways, particularly if the picture is a limiting case or the changes are discrete. In addition, the interpretation of the picture is affected by other factors too, such as the time available for the evaluation, and the mood of the evaluating physician.

Let us look at this problem a little closer. The liver scintigram is a two-dimensional projection of the activity-concentrating hepatic tissue. Independently of the position and form of the liver, an opinion must be given in the evaluation as to the extent of the liver projection too. The liver may have at least 8—10 types of normal form variants, and within the given form the estimation of the size is a subjective judgement based on experience of the pictures, without measurement. Planimetry of the picture is tiring, and in my experience is not done by anyone. In the evaluation it would be good to know the dimensions of the given liver projection is square centimetres, and to be able to classify it into a certain group according to this numerical value.

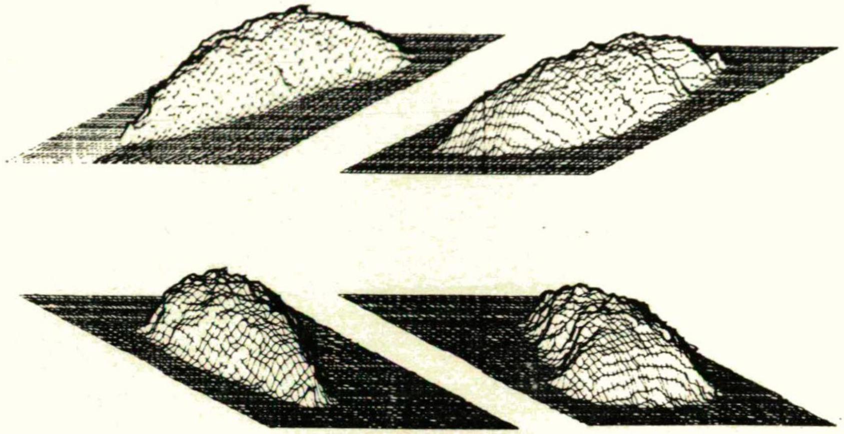

Fig. 2b
Three dimensional picture—normal liver scan

For the machine the calculation of the area of the liver projection in square centimetres is a task requiring only a second or so, and during this time it is also able to calculate the diameters of the liver projection in various directions. The knowledge of the area of the projection permits a more exact estimation of the size of the liver.

Identification of the form of the liver projection can also be performed by machine, by means of the form identification algorithm. Such a type of programme stores the possible normal variants in the memory of the computer, and compares the form of an examined liver scintigram with those of the stored normal variants in a previously determined order. If a difference from the stored forms of ± 5—10% is allowed, then the machine either finds a suitable, similar form during the programme, or there is no such form among those stored. In the former case the machine identifies the examined picture by naming the similar normal form, while in the latter case it records that the form of the examined liver can not be identified with those of the stored variants. This means that the programme has found a new form type, or the form of the examined liver is pathological.

It would be possible to list further partial problems in the objective machine evaluation, and to their possible solution forms. Instead of this, we shall outline in generality that the possibility of complete automation of the evaluation of liver scintigrams depends on whether the necessary tasks can be composed in the language of the mathematical methods and logic. In so far as the corresponding algorithm is found for the solution of every task in this case the automatic, objective evaluation of the pictures can be achieved. Considerable efforts are being made in a number of laboratories all over the world to solve the problem of automatic picture evaluation. The partial results to date promise that it has proven possible to raise the subjective evaluation, which is one of the greatest problems in the scintigraphic procedure, to a mechanical level, so that it may be made *objective*. In contrast with the previous problems, however, this is still a task for the future, and further efforts are required for its solution.

The question can already be raised, however, of what level of evaluation can be expected from the mechanical evaluation programme. If the facts are analyzed realistically, it may be thought that the successfully solved picture-evaluation programme could give an opinion on a very good level for about 90% of the liver scintigrams. It will presumably not attain the level of the best evaluations, but it will certainly exceed those of anyone possessing insufficient practice and experience, and it will even provide assistance to the most expert too. The data calculated with the programme will be of help even to the most routine physician, and will draw attention to lesions which would possibly not have been identified at all, or only on a given day, depending on the level of the efforts or the mood of the evaluator. The mechanical evaluation programme means the peak of the computer technique in the solution of the problems of scintigraphy.

After this outline of the future perspectives, let us finally consider a fifth problem of scintigraphy, which is related to the others but differs from them in its essence and in its solution. Independently of the subjective picture evaluation, the formulation of the information content from the pictures, and the drawing of findings, are likewise subjective activities. With great probability the formulated opinions of two evaluating physicians derived from a given scintigram are essentially completely the same. To exaggerate the problem, it may be said that in a given case the written text may be at least as characteristic of the evaluator as of the lesion. Since the physician indicating the examination is presumably unfamiliar with the evaluation of scintigraphy, even when he is in possession of a copy of the picture he will primarily rely on the formulated opinion when he considers the result as an important or a less important contributing datum in his conscious activity to form a diagnosis.

Very considerable help is provided to overcome the labyrinths of subjective formulation by the application of the computer. In the possible changes in the size of the liver, its form, its position, its capacity to concentrate activity, and the description of the more active or colder regions outside or within the substance are formulated precisely and in an unambiguous way, and if coding symbols are ascribed to the formulated sentences or phrases, then we can construct a mathematical programme which leads, after the feeding in of the coding symbols characteristic of the examined liver, to a continuous text output and finally to a printed finding in the form of a medical finding.

What is the advantage of an opinion formulated with a coding symbol set?

1. The formulation of the finding is clear and unambiguous, and although its style is dry it is free of subjective comparison.

2. The physician performing the evaluation with the coding system is compelled to record every change.

3. It frees the staff of the laboratory from the typing work associated with the findings. The preparation with the fast printer of the computer of the complete

finding, on which the most important data regarding the patient and the employed procedure are given, requires 15—25 seconds.

4. The results of scintigraphy are stored on magnetic tape, which needs little space. There is a possibility at a later date, therefore, for a change characterized by a given coding symbol to be extracted from the complete store of liver scintigraphic results, or for the correlation of a lesion with a parameter defined by any other symbol to be analyzed statistically.

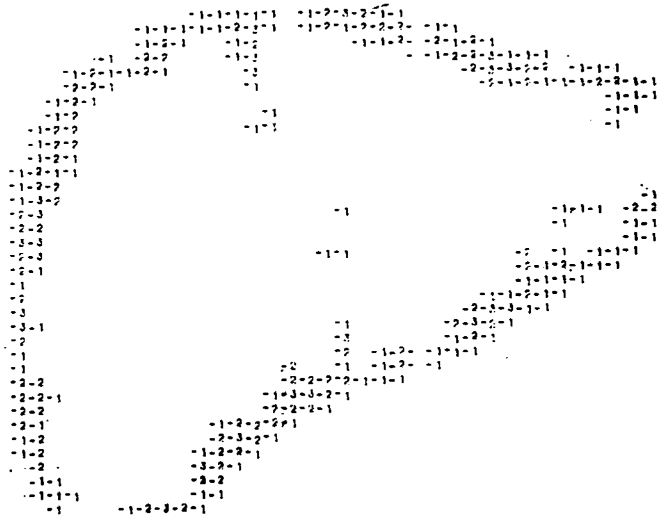

Fig. 3
Residual tabular picture—normal liver scan

After this theoretical and partially practical survey of the computer solution of liver scintigraphic problems and tasks, I should like to show very briefly how computer data processing has materialized in our laboratory.

The first important task in the solution of electronic data processing is the recording of the experimental data in a manner understandable for the computer.

In the outline of the principle of our present system it can be seen that at the same time as the measurement the experimental data of the scintigraph and the automatic sample changer are automatically recorded on paper tape with a perforator. The data measured at other sites and the data identifying and characterizing the patient and the examination procedure are recorded on paper tape on a Siemens telex machine installed in the laboratory, by female assistants specially trained for such perforation work. The data are recorded on the paper tape in the European telex code, and are processed daily in the off-line manner, i.e. separated in time from the measurements, by a Minsk-22 computer in the Cybernetics Laboratory of József Attila University. The computer possesses an 8 K word internal memory, fast data input and perforating unit, and a 6 magnetic tape storage unit. The computer uses a 128-position printer for the reproduction of the calculated results, findings and pictures. An incremental plotter is used to draw out the isointensity lines. Our routine programmes are stored on magnetic tape, and by means of a controlling operational system developed in accordance with the requirements of nuclear medicine, they can be summoned and activated by keying in to the name of the programme from teletype connected to the machine. Magnetic tape is also used for the recording of the results and for the storage. In addition to the off-line processing method, separated in time, we shall be able to achieve simultaneous, on-line data processing too, by means of a direct data transfer line built between the laboratory and the computer.

Apart from the system controlling the data processing, 34 computer programmes have been developed since 1969 in collaboration with my mathematical colleague János Csirik. One third of the programmes ensure the read-in of the data and the display of the results in various forms, while the other, problem-oriented procedures perform the data processing of various concrete isotope diagnostic methods. The residual tabular procedure was developed in 1970 by János Csirik. The method takes into account the distorting effect of the collimator used, and very sensitively identifies regions of decreased or enhanced activity within the substance of the liver. The recording form is also of advantage for the demonstration of cold or hot nodules, because apart from the contour of the organ, symbol groups (in our case numbers with negative or positive signs) are printed out only where a nodule with lower or higher activity than that of the environment is situated. According to the results of the phantom examinations, the method is also suitable for the detection of nodules 2.5 cm in diameter under conditions for which a nodule 3.5 cm in diameter can only be uncertainly surmised on the original image.

I shall now give an account of the results of our previous work. In almost one third of the patients examined by liver scintigraph, neglecting differences in shape and size, clearly negative pictures are obtained as regards the demonstration of cold nodules. In 20% of our cases cold nodules can be identified even in the primary picture; with regard to the resolution of the scintigraph used, these are at least 5—6 cm in diameter. In these cases, therefore, the identification presents no problems. In almost half of the examinations, however, a definite stand can not be taken as to the possibility of occurrence of a space reducing process when the primary picture is inspected. After computer data processing, on the other hand, nodules could be identified on the substance of the liver, or this possibility could be excluded with certainty, in four fifths of these patients. In the remaining one fifth of the doubtful cases the doubt could not be resolved by means of the computer methods. Overall, therefore, it can be said that the accuracy of identification is substantially increased by the electronic data processing, and there is a corresponding decrease in the number of pictures for which a definite opinion can not be given after further careful study.

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