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COMPUTER PROCESSING IN NUCLEAR MEDICINE

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The widespread availability of computers in nuclear medicine has dramatically increased the number and types of diagnostic studies that can be performed. There is no doubt that this trend will continue. In addition, as computer power increases it is likely that in the future analysis of clinical studies will be more sophisticated and automated than they are at the present time.

The purpose of this presentation is to describe the basic use of computers in three areas: Cardiovascular nuclear midicine; Emission computed tomography; and Quality control. In addition, selected new developments in software and hardware that can provide additional information for clinical diagnoses will be described.

Tc-99m labeled red blood cells have been used with physiologically gated computer a number of years to provide important information about cardiac function. From the series of images that represent an average cardiac cycle, ejection fraction, maximum and average rate of filling and emptying can be calculated (Fig. 1). In addition, movies of the heart can be used to

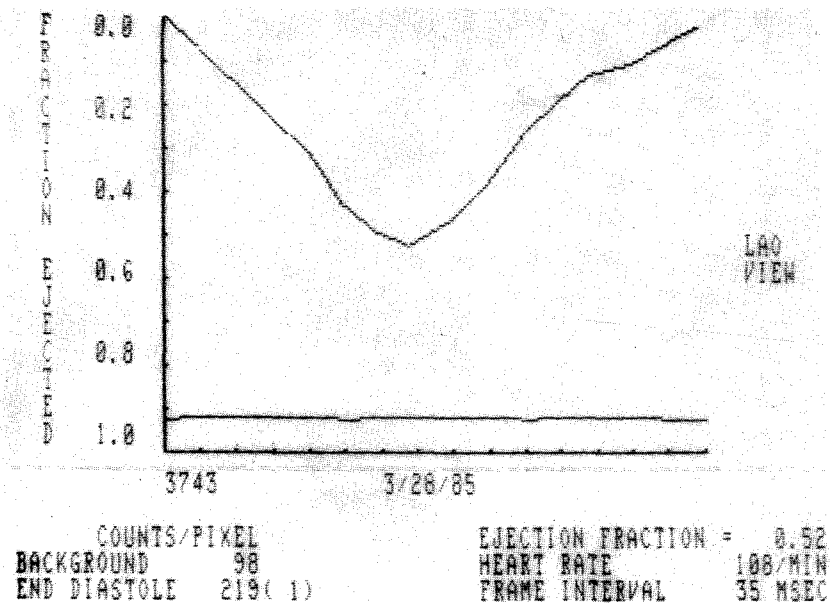

Fig. 1. Volume curve from a left anterior oblique view of a Tc-99m gated blood pool study.

evaluate wall motion and identify areas of akinesis and dyskinesis. A series of images showing the first passage of radioactivity through the left ventricle can be used to calculate cardiac output.

At present the analysis techniques for obtaining these parameters is only partially automated. Searching regions are set by the operator; automatic edge-finding routines are then used to identify edges of the blood pool. Methods are now being develped to fully automate the computer processing [1]. After selecting the patient by name, no further intervention by the operator is required. Initially, the set of gated images is processed to find the minimum count for each pixel, using all frames of the cardiac cycle. The result of this operation is to produce a matrix of values representing the minimum counts in each position, independent of the time when they occurred. After application of a 1:2:1 smooth to reduce noise, the minima are subtracted from all images in the set. The four stroke volume images with the highest center-of-mass (CM) are used to create a composite of atrial end-diastole; the four with the lowest are summed to create a composite of ventricular end-diastole. The atrial composite is subtracted from the ventricular composite to minimize the problem of overlapping structures. The interventricular septum is located by scanning the horizontal profile for a local minimum. After application of an interpolative background subtraction, a 9-point Laplacian operator is used to locate the edges of the left ventricle.

When this processing has been completed, a volume curve is generated. The smoothness of the curve indicates the quality of the edges. A heart rate histogram is also produced which indicates the quality of gating and repeatability of single heart beats. If the histogram is wide or has two peaks, spatial averaging will affect visual and quantitative analysis. Images of the heart at end-diastole and end-systole are used to verify proper operation of the automatic routines[1].

The advantage of this approach is that it provides objective criteria for processing cardiac studies and reduces the amount of operator time that is required. On the other hand, the algorithms are considerably more complex and computer processing time is increased.

Additional information on cardiac function has also been achieved by the use of phase imaging [2,3]. Fourier transform techiniques are applied to gated cardiac studies to produce functional images that display the onset of mechanical systole (pattern of ventricular emptying). In the normal patient contraction begins in the interventricular septum. Patients with right or left bundle branch blocks show abnormal patterns; the ventricles do not contract in phase.

Excrcise cardiac gated studies have been shown to increase specificity [4-6]. However, interpretation of the images is often more difficult because multiple sets of images are acquired for short periods of time and the statistics are poor. Application of Fourier filtering to the images has been demonstrated to improve image quality by virtue of an improvement in the signal/noise ratio [7]. Implementation of Fourier filtering has been hindered by the time required to process gated studies acquired at a number of different exercise levels. This problem can essentially be eliminated by the use of an array processor [8].

Tl-201 is commonly used to evaluate perfusion of the myocardium [9]. Although planar images can be read directly, nuclear medicine physicians feel that computed-processed images are extremely beneficial. The myocardial distribution of Tl-201 can be quantitated by generating circumferential profiles [10]. This is accomplished by performing a radial search for the maximum count rate from a point in the geometrical center of the myocardium. The search is usually per-

formed at 6 degree increments and the results are plotted using rectilinear coordinates (Fig. 2). Results for a series of normal patients are usually superimposed to aid in the interpretation of clinical studies. These techniques have been shown to increase sensitivity and specificity [11].

Overall quality and contrast of TI-201 images can also be improved by the Fourier filitering techniques described earlier [7]. In addition, interpolative background subtraction is often used to improve contrast [12].

The second major topic to be presented in this lecture is emission computed tomography (ECT). it has been demonstrated to improve contrast and the ability to localize structures in three dimensions [13]. Of course, a dedicated computer is required for the acquisition of these images. In addition, ECT provides the potential for quantitation of adionuclide distributions [14]. However, at the present time interpretation of the images is usually not based on quantitative results in single photon tomography.

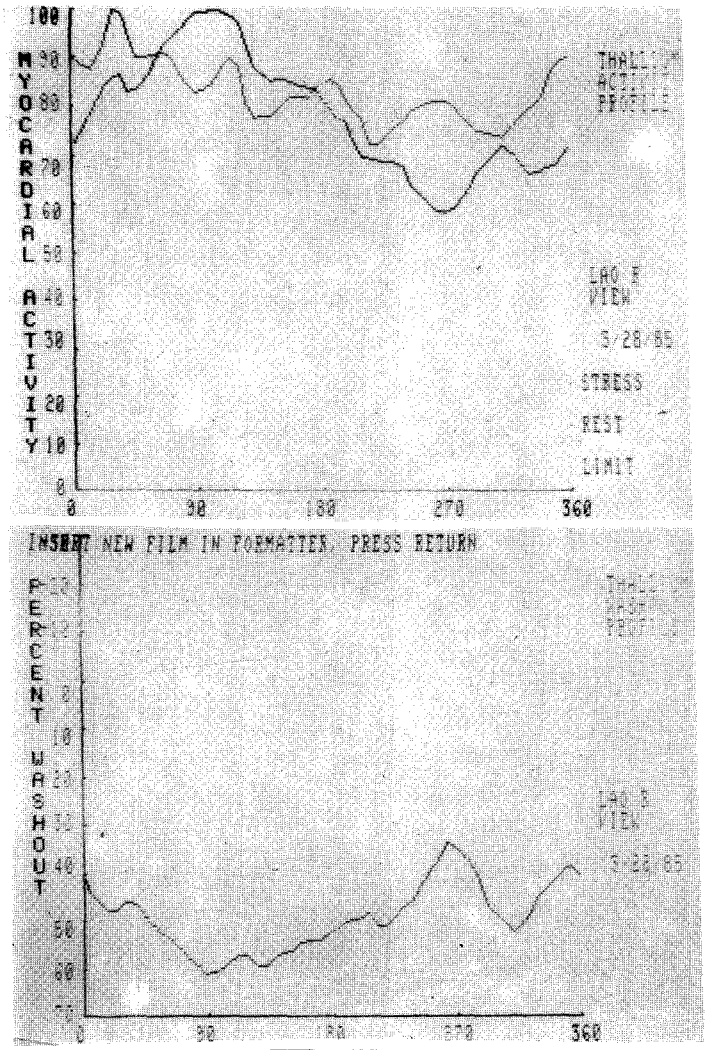

Fig. 2. Circumferential profiles and washout curve for a TI-201 myocardial perfusion study. Bold line represents the stress study; faint line represents the rest study.

Organs that are commonly imaged when planar techniques are used can generally be imaged using tomographic techniques. Recent studies have shown that other pharmaceuticals can be imaged by ECT [15]. Figure 3a shows a transverse section of a patient obtained approximately 45 minutes after the injection of I-123-amphetamine. Because only a small percentage of the injected radiopharmaceutical finally collects in the brain, pre-processing using Fourier techniques in often images (Fig. 3b). Reduction of statistical noise in the projection sets reduces the enhancement of reconstruction algorithms [16].

Post-processing of reconstructed images can also be useful in reducing image noise. In its simplest form, several slices are added together, often after the application of certain weighting factors (Fig. 4). This technique is called volume smoothing. The operation has the negative effect of producing a loss of spatial resolution but may be beneficial when reconstruction noise is a problem.

Garcia et al. have recently presented an improved method for the display of TI-201 images

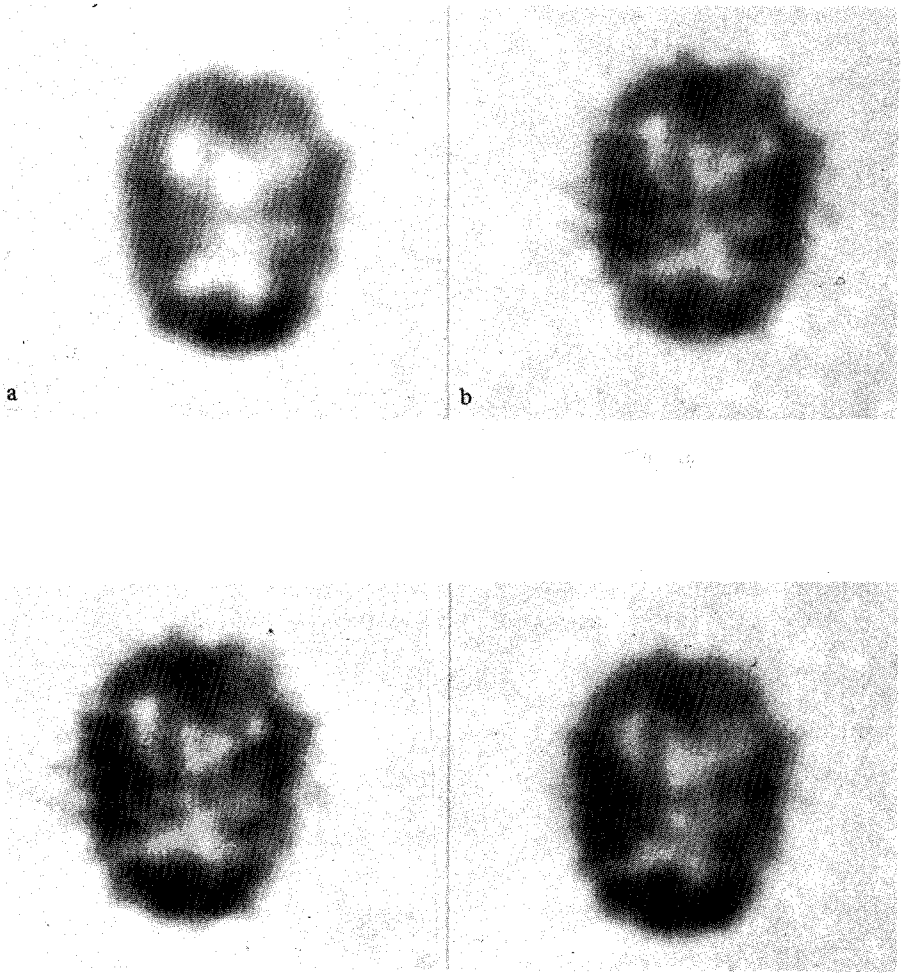

Fig. 4. Transverse section of a SPECT study using n-osopropyl-I-123-p-iodoamphetamine. Right (or Left) image was for a single 0.64cm slice. Left (or Right) image was a volume smooth involving three slices with a 1:2:1 weighting.

obtained by emission computed tompgraphy [18]. Maximum count circumferential profiles of long-and short-axis tomograms are used to define three-dimensional distributions. These are then mapped on to a two-dimensional polar presentation. These data are presented as two separate maps. One is in binary form which shows the extent of the abnormality based on angiographically documented coronary artery disease. The second shows the severity of the abnormality. These data are presented with the apex in the center and the most basal section as the outermost circle.

Positron emission computed tomography (PCT) offers several advantages over single-photon computed tomograpy (SPECT)[18]. First, the use of electronic collimation for PCT significantly improves sensitivity. Second, the ability to use labels found in organic compounds, N-13, C-11, and O-15, greatly expands the range of radiopharmaceuticals that can be formulated. Unfortunately because of the short half-life of these radionuclides, a cyclotron is required on site for their production [19]. Therefore, at the present time, PCT is generally performed only in large medical centers.

One of the radiopharmaceuticals that has proven to be particularly beneficial is F-18-deoxyglucose, which has been used to study glucose metabolism in the brain and heart [20,21]. Apart from the need for computers in data acquisition and processing, the value of these images has been enhanced by the use of computers to form models of metabolism and provide patterns that contribute to the study of patients with Alzheimer's disease, multiple infarct dementia, epilepsy, stroke, and other diseases. Similar principles have been applied to the study of amino acid metabolism in the normal and fasting heart. N-13 ammonia has been used to quantitate blood flow.

The final topic that will be discussed is the use of computers in quality control[22]. They can be used to quantitate field uniformity, spatial resolution, spatial linearity, and sensitivity and present these data as a function of time to monitor changes in instrument performance. Several techniques can be used to evaluate field uniformity. The method described by Keyes et al. involves measuring the number of pixels in the computer image where the counts fall within an acceptable range[23]. A computer image is then generated with pixels outside the acceptable range highlighted. The acceptable range is centered around the average pixel count and is a specified percent of the average pixel count. Extending the acceptable range by twice the square root of the average pixel count can be used to compensate for the Poisson nature of each pixel count. Erickson has described a variation on the method of Keyes et al. which involves only keyboard commands found in most present-day computer systems[24]. The computer images of Keyes et al. provide a subjective interpretation of focal non-uniformities based on the highlighted locations of the pixels outside the acceptable range (Fig. 5). However, focal non-uniformities within the acceptable range will not be highlighted. The Keyes method measures overall uniformity by the number of pixels in the acceptable range.

The use of any one of these measures provides an objective means of evaluating field uniformity. A useful way of comparing these data is to present the results in graphic form as a function of time, as was first proposed by Hasegawa et al.[25]. An alternative approach is to maintain the results in a tablular form for each camera.

Spatial resolution can also be monitored in a more objective way when the computer is used. If a line source is used to measure the full-width-at-half-maximum, and perhaps the full-width-

at-tenth-maximum as well, these data can also be presented as a function of time to monitor camera performance. An alternative is to measure the average modulation for specific spacing of a bar pattern image obtained using transmission techniques.

Proper performance of emission computed tomographic studies cannot be accomplished without the use of quality control procedure[26,27]. Prior to the performance of clinical studies, the center-of-rotation must be determined and appropriate corrections, if necessary, applied in hardware or software. Failure to apply this correction will seriously degrade the resolution of the images that are obtained[28]. In addition, most ECT images require a correction of all the projec-

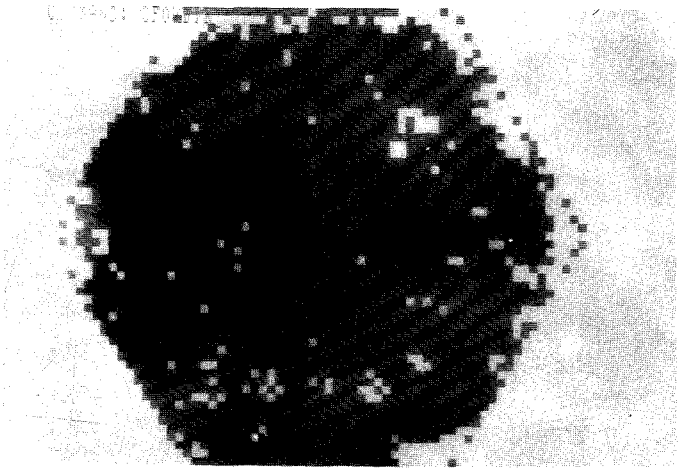

Fig. 5. Computer analysis of a quality control image form an Anger scintillation camera. White squares indicate pixels in the computer image that are above or below the average pixel count plus or minus 5%.

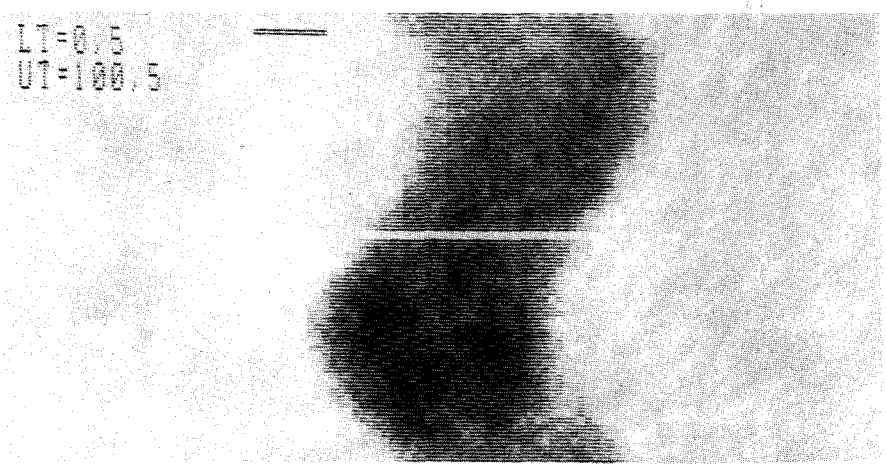

Fig. 6. Sineogram from a SPECT study using n-isopropyl-I-123-p-Iodoamphetamine. One row was taken from each view of the projection data and combined into a single image. The blank row indicates a view that is missing from the set. The black line at the upper left indicates the last view of the complete data set. The four rows above the line are duplicates of the first four at the bottom of the image. Note that a slight movement of the patients head had occurred during the study.

tion data for field non-uniformities[29]. The number of counts that are required in the correction matrix depends on the types of images that are being processed.

Computers can also be used to provide useful information about the set of projections that has been obtained. Sineograms can be produced by taking a specific row out of each projection and presenting the set of slices as a single image (Fig. 6). This image will show instrument artifacts such as missing views and incorrect angles and can be useful in determining whether or not the patient has moved significantly during the study[26].

Conclusion

To perform high quality nuclear medicine studies it is essential that computers be used. In most cases, the commercial vendors supply the software that is required for common applications. It is to be expected that improvements in software and hardware will increase the processing power, and reduce operator and processing time. Quantitative three-dimensional imaging techniques together with tissue sampling will provide additional diagnostic information. Only time will tell the full extent of the benefits provided by computers in nuclear medicine.

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