A Macrofunction for Computer Processing of Comprehensive Renal Function Studies

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Abstract. Details of a series of computer programs associated with a complex renal function procedure, all linked together into a single “macrofunction” are presented. Input consisted of not only in vivo nuclear medicine information, but also data concerning patient identification, urine volumes, voiding time, urine specific gravity, blood pressure and other pertinent information. Computer output consisted of images, curves and typed information presented in an integrated format ready for inclusion into the patient’s record.

Clinical evaluation of this comprehensive renal function macrofunction has proved to be useful, economical, rapid and accurate. It has conveniently sorted a wide variety of disease states and provided clinical information not available from any other non-invasive technique.

Introduction

We previously have reported certain aspects of a comprehensive renal function procedure [1, 4–6] based on data derived from scintigraphy and urine and plasma analysis carried out after a single intravenous injection of $^{131}$I-orthiodiodhippurate (OIH). The test proved to be useful, easy from the patient’s point of view, but complex and multifaceted for the operator.

A series of linked computer programs or macrofunction has been created to maximize accuracy, efficiency, and reproducibility combined with ease of production.

The purpose of this paper is to describe the details of this macrofunction.

Materials and Methods

This technique was based on routine renal study case loads of approximately 10 patients per day, including potential kidney donors, (before and after nephrectomy) renal transplant recipients and patients with a wide variety of kidney diseases from the Urology Service of the University of Alabama-Veterans Administration Medical Center. It was evaluated in 704 consecutive patients from this service. Renal transplant data required special treatment and therefore are excluded from this study.

Patients were studied after an overnight fast if renal artery stenosis was suspected, or they were casually hydrated in all other cases. The patient was placed in a supine position on an imaging table with the kidneys centered over the detector of an Ohio-Nuclear large field of view scintillation camera, attached to a Model 110 console. The blood pressure was taken and recorded.

Adults were injected intravenously with 150 μCi $^{131}$I-orthiodiodhippurate (OIH) (Mallinckrodt) per kidney. The radiopharmaceutical had been checked chromatographically for purity by the technique of Burbank and co-workers [2]. Lots containing more than one percent free iodide were rejected. Children were injected on a dose schedule based on age, which has been previously published [7].

After injection, the patient was imaged continuously for 27 min, after which the patient turned over with the bladder centered in the imaging field, and a 1 min “pre-void” bladder image was made in static mode. (If the patient could not turn himself, the detector was repositioned. At 35 min, the patient voided and a 1 min “post-void” bladder image was made. Blood was sampled at 44 min [9], the blood pressure was again taken and the patient was dismissed.

Data Processing

Scintigraphic data were stored in frame mode on model 150 data systems or in list mode on a model 75 system (both Ohio-Nuclear). Magnetic tapes were sent to the computer for processing.

Plasma harvested from the blood specimen, aliquots of the injected radiopharmaceutical dose and of the urine were counted in Packard Autogamma 5220 or 5230 Autogamma well counter equipped with punched paper tape read-out which were sent to the computer for processing.
Some other data were entered into the computer by keyboard. These included patient identification, height, weight, age, sex, blood pressures, urine volume, and specific gravity.

The computer used in this study was an Informatek SIMIS 4 with 64K memory, disc and magnetic tape, teletype with punched paper tape reader, 8" x 11" oscilloscope, a keyboard console, color television and a high speed line printer.

**Macrofunction Development**

The kidney images were added over the full 27 min and this matrix was displayed on the color television screen. Color was scaled to the highest counting rate in the matrix. Since highest counting rates were often observed over the bladder, this area was masked by the operator to permit color to be scaled to kidney activity.

Accurately drawn regions of interest (ROIs) enclosing each kidney were defined by cursor - a dot which, when moved around the screen, generated a list of contour coordinates for the ROI.

A third ROI was then defined for background subtraction in either one of two ways. Originally, it was drawn by cursor as a triangular area above the left kidney, later it was defined automatically by the computer as a one-cell wide region around the left kidney ROI. The latter method was generally used. The activity in the background ROI of each frame was normalized to the entire field of view, plotted against time and then subtracted sequentially from each scintigraphic frame. After displaying the net 27 min image on the television screen and storage oscilloscope, the computer displayed the three ROIs and generated net time/activity (T/A) curves through them.

The differential fraction contributed by each kidney was calculated by taking the ratio of the integral of the first two minutes of the T/A curves. This fraction was stored. Maximum activity over each kidney was determined and stored. The line printer then listed the minute by minute counts over each kidney and the percent each kidney contributed to the counts.

Next, pre- and post-void bladder ROIs were determined by enclosing the bladder areas seen on the anterior views with the computer cursor and background was subtracted from them as described above. Net counts over each bladder ROI were determined and stored for subsequent calculation.

Effective renal plasma flow (ERPF) was calculated from the plasma OIH concentration by the method described previously by the formula:

\[
ERPF = -99.9 + 10.9x - 0.454x^2
\]

where \(x\) = injected dose (counts/s) \(\times 44\) min plasma concentration \((\text{counts/s/ml} \times 1000)\). ERPF was then normalized to a standard surface area (SA) \([3]\) by multiplying it by \(1.73/\text{SA}\), as suggested by Smith \([8]\]. Differential ERPF was calculated by multiplying the total ERPF by the previously stored differential fraction contributed by each kidney as calculated above.

The percent of the injected dose in the voided urine was calculated and stored. Residual urine volume and percent dose was calculated as described previously \([7]\) by the formulae:

\[
\text{Residual urine volume} = \frac{\text{Millimeters voided urine} \times \text{post-void net bladder counts per second}}{\text{Pre-void net bladder counts per second} - \text{post-void net bladder counts per second}}
\]

\[
\text{Residual percent dose} = \frac{\text{Percent dose in urine} \times \text{milliliters residual urine}}{\text{Milliliters of urine collected}}
\]

Fig. 1. Photograph of a color television computer processed 27 min image, showing kidneys (above) and part of the bladder (below). The computer is programmed to accord count rate intensity with color, however the various isocontour lines created are easily seen in black and white here. This image is created for selection of areas of interest (ROIs) for curve generation and for body background subtraction. These kidneys appear normal.

Total percent dose excreted, defined as sum of voided and residual values was determined. Expected excretion values were calculated from regression equations based on ERPF as previously described \([4, 7]\):

\[
\text{Expected percent dose in urine 35 min} = 17.226 + 0.192 \times \{\text{ERPF}\} + (-0.00015 \times \{\text{ERPF}\}^2).
\]

An excretory index (EI), indicative of the mean transit time, was calculated \([4, 7]\):

\[
\text{EI} = \frac{\text{Percent dose voided} + \text{percent dose residual}}{\text{Expected percent dose excreted}}.
\]

**Results**

The end results of this procedure were presented on a color television screen which was photographed using color polaroid film, on the oscilloscope screen, photographed in black and white and on a page typed by high speed printer for inclusion in the patient's chart.

An example of a 27 min image derived for ROI selection is shown in Fig. 1. This was depicted in color, but shown here in black and white. It afforded a generally adequate visualization of kidney morphology. Figure 2 shows the ROI selection process. The operator-drawn lines to depict kidney outline and a triangular area to represent body background are...