

FUNCTIONAL IMAGING: A METHOD OF ANALYSIS AND DISPLAY USING REGIONAL RATE CONSTANTS

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Functional imaging using regional rate constants can be used to display dynamic organ processes. Positive or negative slopes computed by a least-square fit to a straight line can be selected for varying time intervals and can be displayed in a shades-of-gray format. Using the renogram as an example, focal abnormalities as well as intra-organ transport mechanisms can be identified. The general application of this type of image display is stressed.

Functional imaging is a method by which dynamic processes may be represented by a single display (1,2). It is designed to compress into a single image information ordinarily acquired and recorded by a series of predetermined elapsed time or fixed count scintigraphs. The single image has the obvious advantage of synthesizing large amounts of data and of identifying processes not apparent by simple inspection and comparison of multiple images.

Because of its widespread familiarity and application, the ^{131}I -Hippuran renogram is a good example of our approach to functional imaging using a scintillation camera. The method to be described, however, is applicable to other dynamic systems. The image acquired is of special value since regional information can be displayed. Regional information is often obscured by total organ or system measurements, a common phenomenon, as evidenced for example, by normal liver function in the presence of multiple metastases and normal pulmonary function with focal emphysema. The major advantage of the regional functional image is its ability to identify compartmental shifts and time-dependent focal abnormalities and to eliminate cumbersome and often inaccurate serial imaging methods.

Dynamic function can be expressed in terms of rate of change. The complexities of the dynamics of Hippuran processing by the kidney lead one to model

the time properties with exponential function (1,2). For simplicity, however, linear approximations over short time intervals can provide useful dynamic information. This approach allows quick computation of rate constants for each matrix element within the entire digitized gamma camera imaging field. The computed rate constants are then compared with each other and displayed in computer matrix form using a simulated 16-level shades-of-gray format. The final conventional computer-produced image is indicative of the regional dynamics of the organ, and the regional accumulation or loss of ^{131}I -Hippuran for the chosen time interval.

METHOD

Gamma camera images are obtained over the lower back with the patient in a comfortable, erect, sitting position. A dose of 300 μCi of ^{131}I -Hippuran is injected. Twelve-second frames of data in 32×32 matrix form are acquired for 20 min by a Digital Equipment PDP-12A minicomputer. After the data have been acquired, a sufficient number of data frames are summed during replay to form a composite image from which gross areas of interest encompassing each kidney as well as a background area can be identified for computation of renogram curves. The two renogram curves and the background curve are plotted for overall identification of the dynamics of Hippuran processing.

The SLOPE program computes a least-squares fit of data in every bin for any sequential ten frames of data. The fit is to a straight line of the form $Y = aT + b$, where a is the parameter of interest. Depending on the nature of the data and the ten frames over which the computation is made, a is

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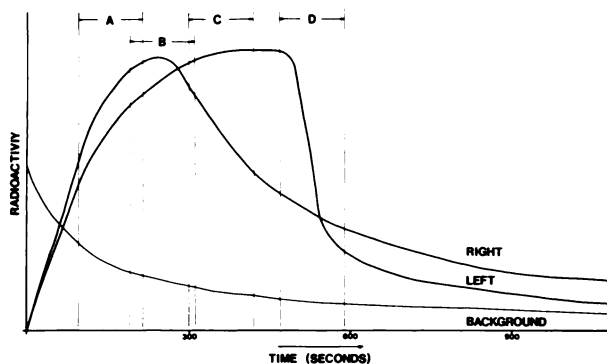


FIG. 1. Renogram curves for Case 1 obtained by area-of-interest counts over each kidney minus background. Segments A, B, C, and D indicate time intervals from which computations were made to produce corresponding images of Fig. 2.

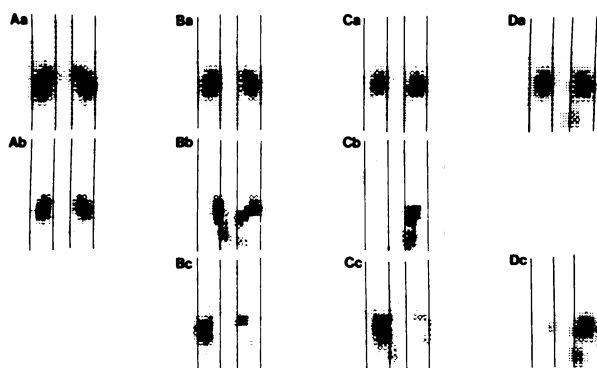


FIG. 2. Summation (a), upslope (b), and downslope (c) functional images corresponding to time intervals of renogram curves of Fig. 1 (A, B, C, and D). Labels indicate right side.

either positive or negative. In the initial portions of the renogram curve, kidney areas are accumulating Hippuran while background areas are losing Hippuran. Displaying only the positive slopes provides a good visual separation of kidney from nonkidney areas during this interval. The display of the slope is selected during the operation of SLOPE to be either positive or negative. Either the positive or negative data are normalized to match a 16-level shades-of-gray scale to form the functional image of accumulation rates in Phase I and II and excretion rates in Phase III of the renogram curve.

RESULTS

A detailed examination of two illustrative cases demonstrates the value of the functional image form.

Figure 1 is the area-of-interest renogram for left and right kidneys, each after removing background. The accumulation rate of Hippuran of the right kidney appears normal. A transient plateau characterizes the left kidney curve suggestive of a temporary obstruction. Starting times for the slope computations

were selected from these curves. Each display presents 120 sec of information (10 frames at 12 sec/frame). The top row of Fig. 2 is the direct summation of counts accumulated during the interval, the middle row is the positive slope display, and the bottom row is the negative slope display. The capital letters of each image correspond to the time intervals marked on Fig. 1.

Figures 2Aa and 2Ab display the total accumulation and the uptake rates respectively from 96 to 216 sec (Interval A of Fig. 1). Both kidneys are evident and symmetrical with respect to regional and total accumulation and uptake rates. Decreasing background activity, obvious on the summation study of Fig. 2Aa, is erased by the positive slope nature of the display in Fig. 2Ab.

The displays of Figs. 2Ba, 2Bb, and 2Bc represent the interval from 192 to 312 sec (Interval B of Fig. 1). This interval brackets the peak of the right kidney curve. Figure 2Ba is again the summation of activity within all frames in this interval. Both kidneys are clearly outlined and their location is easily identified. Since the total activity summated for each compartment during this interval of collection is equal, the summation displays are symmetrical and do not identify differences in intrarenal transport. The positive slope display (2Bb) identifies accumulation within the pelvic and ureteral portions of both kidneys. On the left side, in contrast to the right, there is continued but reduced accumulation in the cortical region (Fig. 2Bb). The negative slope more clearly shows the rapid loss of the labeled Hippuran from the right kidney cortex and medulla (Fig. 2Bc).

Figures 2Ca, 2Cb, and 2Cc show a similar set of displays over the interval 300–420 sec. This time interval brackets the negative slope portion of the

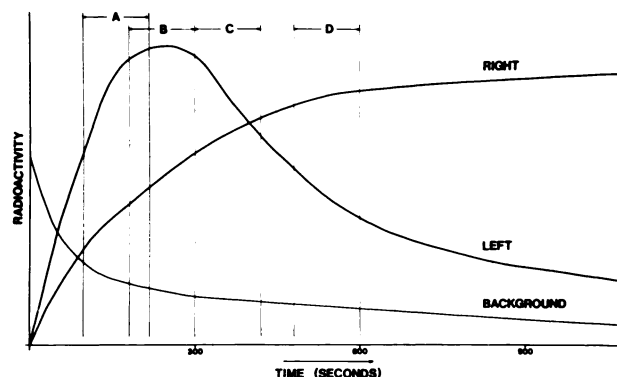


FIG. 3. Renogram curves for Case 2 obtained by area-of-interest counts over each kidney minus background. Segments A, B, C, and D indicate time intervals from which computations were made to produce corresponding images of Fig. 4.

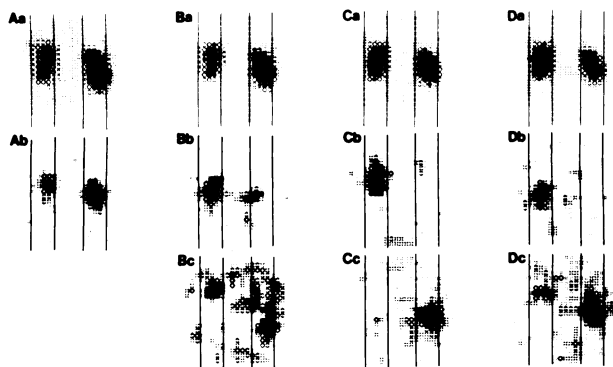


FIG. 4. Summation (a), upslope (b), and downslope (c) functional images corresponding to time intervals of renogram curves of Fig. 3 (A, B, C, and D). Labels indicate right side.

right kidney and the flat portion of the left kidney (Interval C of Fig. 1). During this time interval, no significant right kidney accumulation occurs. At the same time, Hippuran increases in the left kidney pelvis and ureter. The negative slope display shows Hippuran being removed from the entire right kidney as the dominant change in concentration with very little being removed from the left kidney.

Figures 2Da and 2Dc cover the interval from 468 to 588 sec and brackets the rapidly decreasing section of the left kidney curve (Interval D of Fig. 1). Figure 2Da, the summation picture, still shows both kidneys, indicating that all Hippuran has not been removed. The negative slope of Fig. 2Dc indicates the rapid rate of removal from the pelvic region of the left kidney as well as some transport out of the left ureter.

In this minimally abnormal case, the functional display provides a mechanism for identifying intrarenal transport. The initial accumulation of Hippuran in both kidneys is approximately equal. Over the inflection point of the right kidney curve (Interval B), Hippuran can be identified accumulating in the pelvic region of the right kidney (Fig. 2Bb) and out of the cortex (Fig. 2Bc). Within this kidney, two distinct processes are going on simultaneously, acquisition and removal. On the left, there is continued accumulation in the left cortical region in the time interval of Fig. 2Bb. Later (Fig. 2Cb), the dominant change in concentration is left pelvic accumulation. This suggests an obstructive process, but one which is only temporary as shown by the rapid removal rates of Fig. 2Dc.

A second example of functional imaging of the kidneys where the renogram curves show wide disparity is seen in Fig. 3. There is definite obstruction to the outflow of the Hippuran from the right kidney. The left kidney curve is normal.

Figures 4Aa and 4Ab are taken from 96 to 216 sec (Interval A of Fig. 3). The summation of activity and the rates of uptake are dissimilar and indicate reduced Hippuran accumulation by the right kidney. Figure 4Ab shows elimination of background due to its negative rate of change. Figures 4Ba, 4Bb, and 4Bc correspond to the time about the inflection point at the peak of the left kidney curve (Interval B of Fig. 3). The right kidney is still accumulating Hippuran in its lower portion while the left kidney is acquiring Hippuran primarily in the pelvic region (Fig. 4Bb). In the negative rate image (Fig. 4Bc), Hippuran is disappearing from the cortical area of the upper pole of the right kidney and from the cortical region of the left kidney. The negative slope of the background activity is also apparent.

The summation of activity represented by Fig. 4Ca shows nearly identical appearances of both kidneys (Interval C of Fig. 3). Based on this single isolated frame, equivalent to a scintiphoto of the interval 300–420 sec after injection, both kidneys appear the same. Yet, Fig. 4Cb shows only the right kidney accumulating Hippuran most evidently in the lower pole while Fig. 4Cc shows primarily the left kidney excreting Hippuran. This represents a distinct and discernible separation of temporal function of the left and right kidneys.

Figures 4Da, 4Db, and 4Dc are from the interval 480–500 sec (Interval D of Fig. 3). The lower portion of the right kidney is still accumulating Hippuran (Fig. 4Db) while the upper portion shows a slightly diminished concentration (Fig. 4Dc). The left kidney is very obviously excreting Hippuran from the kidney pelvis (Fig. 4Dc).

The regional functional images of Fig. 4 identify the normal mechanisms of Hippuran accumulation and elimination by the left kidney and the obstructive pattern on the right side. The obstruction affects mainly the lower portion of the right kidney.

DISCUSSION

Positional and geometric problems have been considerably reduced when renogram curves are generated by scintillation camera area-of-interest instrumentation. The renogram curve obtained in this fashion, either by tape or computer-recorded data, graphically identifies gross organ function. Each point on the curve is the resultant of the activities of multiple compartments within the region defined by the area of interest. The use of the matrix form enables regional function to be analyzed. For the renogram, Hippuran activity for each matrix element is evaluated in terms of its relative slope, either increasing or decreasing. The slope parameter is computed using a least-squares fit to a straight line

for each element. The functional image then is a display of the range of computed slope values.

Information displayed by the functional images requires considerable study for proper understanding. Each of the images in Figs. 2 and 4 is displayed with independent gray-shade scaling factors. Thus, it is not valid to observe equivalent densities in Figs. 4Cb and 4Cc, the upslope and downslope images, respectively, and conclude that Hippuran is leaving the left kidney as rapidly as it is entering the right. Each of these figures has an independent scale factor. It is valid to interpret, however, that the accumulation rates in the pelvic region of the left kidney and grossly in the right kidney are similar in Fig. 4Bb.

Each of the slope values is computed on ten data points. In a study of the kidney, this means that 120 sec of data are summarized in the display. If the rates of transport within a given organ were faster, either the number of data points would be reduced for slope computation or the sampling interval shortened.

The functional image composed of regional rate constants may be adapted to other physiologic process and organ systems. The use of the ^{131}I -Hippuran renogram serves only to emphasize the kind of information which can be extracted from this display. The single functional image contains considerable information and yet is easy to interpret.

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