

Computing adrenal uptakes with compact, fixed-size regions

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In planar nuclear medicine imaging of the adrenal gland, there are three requirements for an uptake determination: finding the region of interest, subtracting 'background', and converting cps to μCi . A computer program that covers each requirement is outlined. The region of interest is determined by a nearest-neighbor region-growing technique. It starts from an operator-chosen center, searches for the hottest pixels, and terminates when a fixed-size region is found. If the resulting region is unacceptable, recourse to a second level of searching, which produces a more compact region, is possible. Background from underlying and overlying tissue is estimated from the average counts/pixel in a narrow 'ring' surrounding the adrenal. Conversion to μCi is carried out by use of a calibration equation which requires a value for the adrenal depth. This value may be obtained from a lateral view.

The program is available in listing form. For use with a Medical Data Systems A² computer, files can be transferred directly. Parameters which should be changed for the use of the program with another camera-collimator system are noted.

Background subtraction Nuclear medicine Region-growing Region of interest Uptake

1. INTRODUCTION

In planar nuclear medicine imaging of the adrenal glands, whether a cortical [1,2] or a medullary [3] gamma-emitting radioisotope is used, quantification of the uptake requires:

- (i) Determining the region of interest in the fixed-time projection image.
- (ii) Summing the counts within that region of interest and subtracting an estimate of the 'background' which is included.
- (iii) Relating the resultant number of counts detected in a fixed time to the number of μCi of radioisotope actually taken up by the gland or tumor. Such a calibration involves taking into account the effects of absorption and scattering of the gamma-rays as they emerge from the body.

Adrenal images generally are low contrast because of uptake in the liver and in body tissue and

are noisy because usually < 1% of the dose comes to reside in the glands or tumor. These image features make it very difficult to use edge detection algorithms to delineate the region of interest.

In this paper, we will outline an approach to the uptake problem that has been in use at the University of Michigan since it was introduced 5 years ago [4]. This approach now uses a region-growing algorithm that has two levels. At level 1, the algorithm searches out the 'hottest' pixels near a starting pixel to be categorized as adrenal points. It sometimes happens that the adrenal is poorly resolved from an adjacent structure and this level 1 searching includes obviously non-adrenal areas. Two years ago a second level of searching was added to cover this case. At level 2, a further constraint toward circular regions is imposed. This constraint is only invoked if level 1 searching fails because if it was used for all adrenals, the tendency would be to avoid prolate shapes in favor of circular shapes even in cases where the adrenal is well resolved from nearby structures. Recently the

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entire program has been adapted to a Medical Data Systems (MDS) A² computer and the routines are now available.

2. METHODS

The basic image for determining adrenal uptake is a 20 min posterior image taken with an Anger scintillation camera and a high-energy parallel-hole collimator. The region of interest is determined by a nearest-neighbor region-growing technique. The starting point for the region growth is a center chosen by the operator; then the computer takes over, eventually stopping the growth after a fixed number of matrix points has been selected as belonging to the adrenal. The number of counts within the region is found by summation and the 'background' within the region from underlying and overlying tissue is estimated by finding a value for background counts/pixel. This value is determined from points surrounding the adrenal image, under the assumption that the background across the image is smoothly varying. This assumption, that there is no depression in the background profile at the location of the glands due to a deficit of background-emitting tissue, is reasonable because the adrenals are small compared to the body thickness. Such a depression has been reported for heart planar imaging [5]; however, that organ is a much larger fraction of the body thickness than is the adrenal. The calibration method that allows conversion of cpm to uptake in μCi is based upon a phantom measurement [1,6]. It is necessary to assume an adrenal depth or to take a lateral image with a radioactive marker placed on the back to determine the depth.

2.1. Compact, fixed-size region of interest

The starting point for the active part of the algorithm involves the operator sequentially positioning an x -axis and y -axis cursor over the center of the pertinent adrenal (uptakes for a single adrenal or a pair of adrenals can be found). The program then categorizes this pixel as part of the main adrenal (category 1) and the 8 nearest-neighbor pixels as tentatively being adrenal edge

elements (category 2). It then checks that the current number of adrenal pixels (9 at this point) is not greater than or equal to the predetermined size number. If it is not, it checks all category 2 elements for the one or more with the largest number of counts. These elements are updated to category 1 and their 8 nearest neighbors are added to the adrenal (in category 2) if they are not already categorized. The algorithm repeats in this way until the predetermined number of pixels is achieved. (A slight variation is required at the endpoint so that the number is attained exactly.) Figure 1 shows the progress of the region growing over 3 cycles for a given data set. For the example, 20 pixels are to be found and the algorithm reaches this number after exactly 3 cycles. (Thus, the endpoint algorithm variation is not illustrated.)

At this point in the program, the image is displayed with the selected adrenal region designated by a surrounding black band and the operator is asked if the region is acceptable. Usually the region is quite compact but it can feature a 'flare' going off in a particular direction. This occurs, for instance, when the right adrenal merges with the liver and the algorithm tracks into the liver region and stays there. (This is common in dexamethasone-suppression adrenal scanning; see the example in [2].) If the search features such a flare and thus has failed, the operator can return that the result is unacceptable and the algorithm goes to a second level of searching. This level is like the first except that the algorithm chooses new adrenal points not on the basis of counts alone but on the basis of counts inversely weighted by the square root of the distance from the adrenal center. At the end of this searching, the chosen region is again displayed and the operator queried as to its acceptability. (As a modification of the program, the exact power of the distance can be varied to more or less guarantee a selected region that is compactly located around the center which was originally chosen by the operator.)

The fixed number of pixels which terminates either level of searching corresponds to an area of 17.3 cm^2 (108 4-mm-square pixels). The choice was made empirically as that number which, at level 1, led to regions that included as much of the adrenal as possible without allowing the region to track

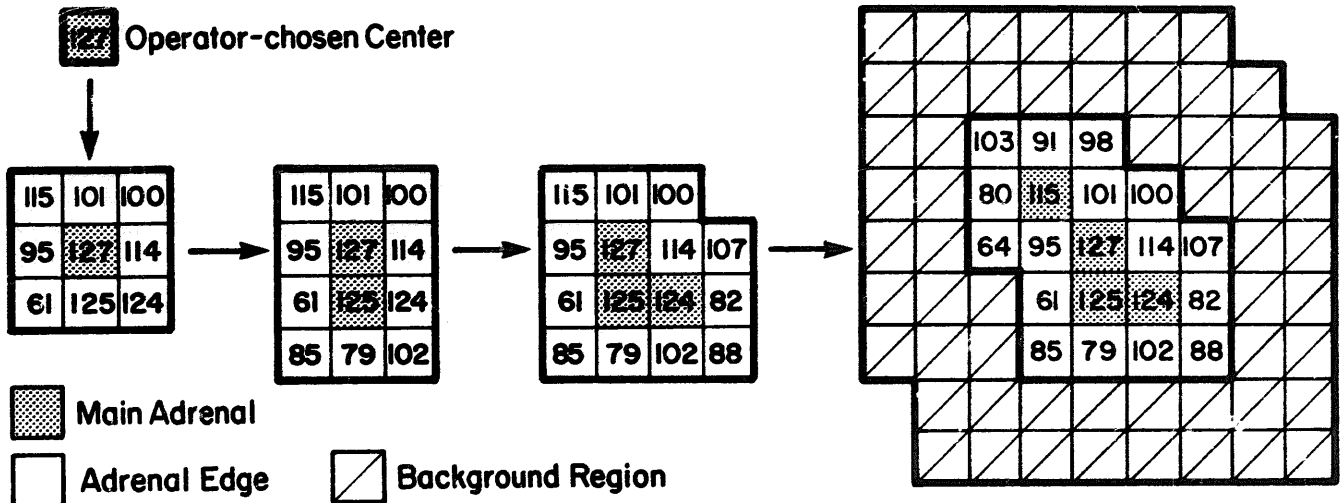


Fig. 1. Progress of region growing over 3 cycles with level 1 searching. The algorithm starts from the operator-chosen adrenal center and cyclically adds the hottest pixels to the main adrenal while updating the adrenal edge. After the adrenal region is found, as indicated by the inner thick black line in the figure at the right, a 2-pixel-wide background region is defined. In real applications, the algorithm cycles more times and the resulting regions include a larger number of pixels.

into other structures in a significant fraction of the patient population. (This population is that represented in [4].) Note that due to the finite resolution of a scintillation camera, a reduction of, for example, 25% in the geometric projected area of the adrenal would reduce the required image region of interest (and thus the number of pixels) by < 25%. Thus, the sensitivity of the method to different size adrenals is argued to be less than one might expect.

2.2. Background estimate

After the region of interest is selected, the algorithm finds the region to be used for estimating background by expansion from the adrenal edge points (category 2). The 24 first and second nearest neighbors of each of these points are assigned to the background estimate region (category 3) if they are not already categorized (see right-hand-side of fig. 1). (It is the background region which forms the irregular dark ring around the region of interest to delineate it for display.) The counts in the background estimate region are then averaged to obtain a background counts/pixel which is effectively subtracted from each counts/pixel value

in the region of interest. The uptake in counts is then the sum of the corrected values in the region.

2.3. Calibration

Before the uptake in counts is converted to one in μCi , an assumed value for the depth of the adrenals in cm is accepted or recourse is made to a lateral image on which cursors can be placed by eye over the adrenal pair and over a marker on the skin so that depth can be calculated. The calculated depth equals the distance in pixel times the camera scale in mm/pixel. We currently use only a single depth for both adrenals even though measurements on normal subjects have indicated that the left adrenal is an average of 1.8 cm deeper than the right [7,8]. A change in the program could easily take such a difference into account if there were an easily applied technique for determining it for each patient. This depth calculation, as well as the region of interest conversion from the fixed area in cm^2 to number of pixels, requires a previous measurement of the camera scale. Our current value for this scale is 5.0 mm/pixel for 64×64 acquire. Changing this value requires a program modification and recompilation.

Given a determination of the adrenal depth, the

ADRENAL UPTAKE
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PATIENT:      TEST      STUDY NAME: 72HR MIBG
IMAGING DATE: 11/19/81  DATE INJECTED: 11/16/81
DOSE INJECTED: 1000 UCI  NUCLIDE: 113I
ACQUISITION TIME: 20 MIN.  CAMERA: ON
ORGAN DEPTH:  LEFT 7.92 CM  RIGHT 7.92 CM

UPTAKE:  LEFT - 0.05      S.D. RANGE: 0.01
         RIGHT - 0.04     S.D. RANGE: 0.01
         TOTAL - 0.09

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Fig. 2. Sample output: Uptake and 1 SD are given in units of % of administered dose corrected for decay to date of imaging.

conversion to uptake in μCi is carried out as outlined below: For a 1000 hole medium-energy collimator and a 20% window, a phantom measurement [1,6] established that the effects of attenuation and scatter are accounted for by an exponential equation:

$$R = \frac{1}{\alpha} S e^{-\mu x}$$

where R is the count rate in cpm, S is the source strength in μCi , μ is an effective absorption coefficient,

x is the depth below the skin surface and α is a suitable proportionality constant. For ^{131}I and our camera system, the current $\alpha = 0.00429 \mu\text{Ci min}$ and μ is 0.10 cm^{-1} , a value between that of water and fat. For a different camera-collimator system, the calibration can be redone. However, we expect the value of μ is unlikely to change much and the value of α can itself be re-evaluated more simply as follows: One places a syringe containing a known number of μCi , S_0 , on the collimator face and records the count rate, R_0 . One then solves the equation above for α with $x = 0$:

$$\alpha = \frac{S_0}{R_0}$$

Insertion of a new α again requires program modification and recompilation.

To obtain the % of dose, the calculated value for S is divided by the initial dose in μCi (a program input) corrected for decay to the day of the measurement (also a program input).

A sample output is shown in fig. 2. The standard deviation range shown at the right contains only the Poisson statistic errors propagated through the calculation. Other errors have not been estimated but would tend to make the error value larger than the one listed. Also, we have noted that varying the size 10% or 20% about the empirical value chosen does not have a large effect on the uptake.

TABLE I

File name	Subroutine name	Function
UPTAKE *	MAIN	64 × 64 image mode
UPI28	MAIN	128 × 128 byte image mode
BACKPLOT	PLOT	Displays image
BACKASC	NUMASC	Converts number to ASC II
UPIST	NPST	Provides image specifier table
UPFIND	FIND	Unpacks a word
UPCGNV	CONVERT	Converts image from byte to word
BACKERR	ERROR	Error handling routine
ADUPAN64	WORK	Adrenal edge detection and uptake
ADUPAN128	WORK128	Same for 128 version
ADUPBN64	SQUARE	Checks 8 nearest neighbors for adrenal edge assignment
ADUPBN128	SQR128	Same for 128 version
ADUPCN	BKGND	Checks 24 first and second nearest neighbors for background assignment
ADUPCN128	BKG128	Same for 128 version

* All file names have suffix .FR

4. HARDWARE AND SOFTWARE SPECIFICATIONS

This program is user interactive and prompts the operator for pertinent data. Two versions are available for the MDS A² user: one for 64 × 64 byte or word mode acquisition and one for 128 × 128 byte mode acquisition. A list of the files involved is given in table 1. Patient images are selected from those available on the patient list and the numbers for the posterior and lateral images of interest should be found before entering the program. The 64 × 64 version takes 6 s searching time/adrenal at level 1, and 10 s in addition/

adrenal for level 2; the 128×128 version searches for 4-times as many points and takes considerably longer than 4-times as long because of repeated unpacking of a word into 2 bytes. The program uses an overlay of the main subroutine and the display subroutine and so fits into the 26 kilowords allocated to one terminal (32000–6000 words for operating system). The main subroutines, in FORTRAN, could be converted to a system other than the MDS A².

5. PROGRAM AVAILABILITY

The programs are available in listing form. For potential MDS users who can supply a 2.5 megabyte front-loading cartridge disk, or 10 in. magnetic tape, the files could be transferred directly.

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