A RAPID METHOD FOR EVALUATION OF REGIONAL CEREBRAL BLOOD FLOW AFTER INTRA-ARTERIAL INJECTION OF ^{133}Xe

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A technique based on the stochastic method is described for the computation of regional blood flow (RBF) after intra-arterial injection of ^{133}Xe. Results are presented on scintigrams, defined by 600–800 channels in a 64 × 64 matrix. The content of each channel is equal to the computed RBF value. The standard deviation is also computed for each channel. The total computation cycle is achieved within 10 min. The method has been used to investigate the influence of anesthesia or drugs on regional blood flow. For this purpose, a differential printout program was written in which variations of RBF values between the two measurements are expressed in units of a fixed percentage; provision is made for calculation of RBF variations in units of differential standard deviations. Data are in good accordance with other clinical findings. This method is suitable for clinical use when blood flow values in gray and white substances are not requested.

Since the introduction by Lassen and Ingvar (*1*) of their method for measuring regional cerebral blood flow, several improvements have been made in order to minimize measurement errors, to estimate standard deviations, and to reduce computation time (*2*).

The bicompartmental method applied to numerous regions of interest is extremely time consuming even with very sophisticated systems and this constitutes a problem in clinical practice.

The purpose of this paper is to describe a simple and rapid method that, within 10 min of completing the storage cycle, provides a clinically useful image of regional blood flow (RBF) in the whole hemisphere.

METHODS

A gamma camera coupled to a Tridac-M system with a storage memory of 2 × 4K is used. It is connected to a minicomputer Multi 8 of 16K octets memory capacity.

After injection of 4–5 mCi of ^{133}Xe, dissolved in 1.25 ml saline, into the internal carotid artery, the fractional images are stored on magnetic tape (*3*) (time increment: 5 sec, total time: 12 min) according to a technique similar to that of Heiss, et al (*4*).

Particular care is taken to maintain steady physiologic parameters (p_{CO_2}, arterial blood pressure) before and during the whole examination (*5*).

The rapid analysis of the results is based on the stochastic method (*6,7*) adapted for computer processing, which assumes that

$$F\,(\text{ml}/100\,\text{gm}/\text{min}) = \frac{H_{max} - H_{10}}{A} \times 100 \times \lambda_c$$

where F is the regional blood flow (RBF), H_{max} is the maximum counting rate (initial peak value), H_{10} is the counting rate 10 min after the initial peak value, A is the total number of counts collected between the time T (H_{max}) and the time t (H_{10}), and λ_c is the blood-tissue partition coefficient, corrected for hematocrit. This equation is suitable for the data collected in every channel of the 64 × 64 matrix. The computed image provides two items of information: first, the distribution of blood flows in the brain and second, their absolute values within the precision limits of the method. The accuracy depends on accuracy of the counts and on the validity of the empirical formula.

At the same time, the standard deviation is computed for each channel and stored in the second part of Tridac memory. In order to maintain all noise on an acceptable level, the intermediate images used during computer processing are smoothed by a weighted spatial averaging in a 3 × 3 matrix configuration. If electronic noise is very high, the

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smoothing is preceded by a data bounding in which the contents of one isolated matrix element can be replaced by the mean value of its eight neighbors.

The two images (RBF and corresponding standard deviation) can be either visualized as a scintiphoto, stored on magnetic tape, or printed out by teletype and compared with other results.

The knowledge of the standard deviation for each channel allows one to check the statistical significance of any recorded variation in blood flow.

A procedure has been devised (Fig. 1) that needs no extra buffer memory capacity due to the appropriate use of the storage memory and of the existing buffer zones in the computer memory. The computer program, written in assembler language, needs only a few hundred octets using existing subroutines. The subroutine that calculates the standard deviation is the most time consuming.

RESULTS

An integration time of 10 sec was used for determining the H_{max} and H_{10} values. A standard deviation of less than 20% was obtained for most RBF values. It was greater at the periphery of the computed image, but these regions are of less clinical importance. The standard deviations are comparable with those obtained for a classical scintigraphic image defined by about 25,000 counts distributed over 800 channels, which is the normal definition of a typical RBF image. We tested the method for reproducibility on material described in a previous paper (*3*), the results of which had been stored on magnetic tape.

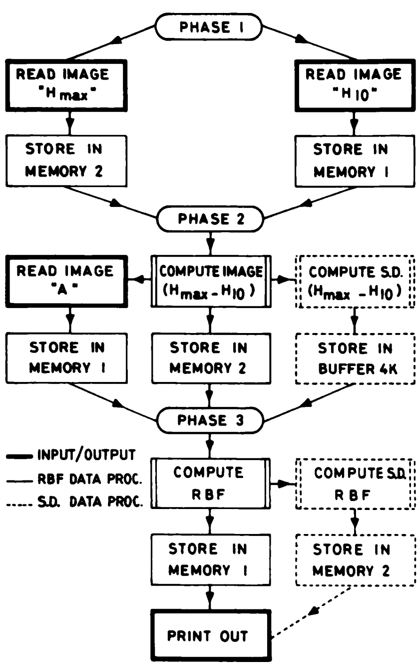

FIG. 1. Complete computing cycle consists of three phases. Each phase represents complete storage cycle, allowing computation of intermediate or final result. Memory 1 and Memory 2 refer to storage memory 2 × (64 × 64).

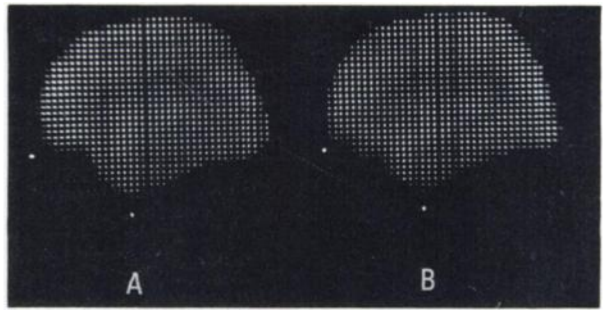

FIG. 2. Patient MV, 53-years-old, experienced several transient ischemic attacks (right hemiplegia). Left carotid angiogram was normal. (A) first measurement; (B) second measurement made under same conditions (1 hr later).

FIG. 3. Differential printout of images in Fig. 2. Difference between two images is expressed in units of 20%. Print code is as follows: · is difference less than ±20%; 1, 2, 3, . . . , 9 is positive difference in units of 20%; + is more than + 9 units of 20%; A, B, C is negative differences in units of 20%; and — is more than — 3 units of 20%. First measurement is taken as reference image. Compression of printout images is due to fact that on our teletype, line spacing is greater than character spacing.

Figure 2 is a scintiphoto of two RBF images resulting from two consecutive records that were taken in identical conditions but with an interval of about 1 hr between them. A differential printout (Fig. 3) shows that the difference between the two measurements is less than 20%, which is in good agreement with the computed differential deviation. As described before, the computer calculates for every RBF value its corresponding standard deviation and therefore it should be possible to determine the exact differential standard deviation for each channel. The reason for using a fixed differential standard deviation (20%) in the printout is purely a practical one based on limitations of storage memory and computer memory.

The method described here was used to investigate the influence of Halothane anesthesia on RBF for a set of material reported in a previous paper (*5*). In the case of a patient who developed a transient left hemiplegia, the RBF image obtained during Halothane anesthetization (Fig. 4B) differed from the RBF image at rest (Fig. 4A) in that the RBF decreased more in a previously ischemic region. The

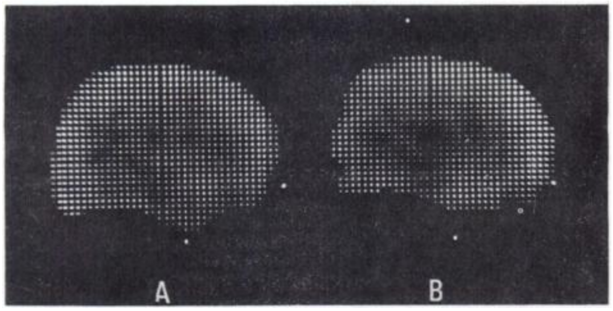

FIG. 4. Patient AF, 17-years-old, developed transient left hemiplegia. Right carotid angiogram showed complete obstruction of middle cerebral artery. (A) measurement at rest; (B) second measurement made under 1% Halothane anesthesia.

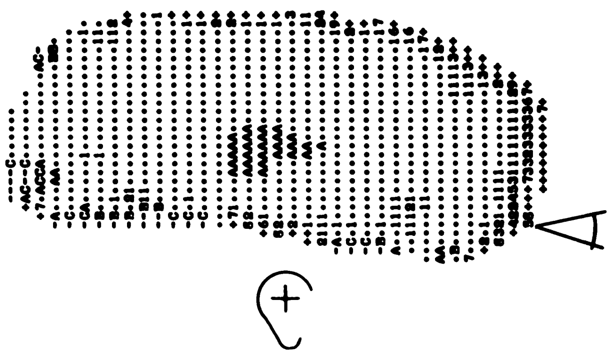

FIG. 5. Differential printout of images in Fig. 4. Image shown in Fig. 4A is taken as reference. Print code is same as in Fig. 3. Pathologic region is clearly defined by print of "As;" i.e., 20–39% decrease of RBF after administration of anesthesia.

differential printout (Fig. 5) revealed clearly that the decrease was more than 1 s.d. in the pathologic region: the anesthesia produced a "steal syndrome."

DISCUSSION

The results obtained by this method are readily interpretable by the clinician. The scope display gives an image in which brilliance in every point of the 64 × 64 matrix is proportional to the local blood flow. Hypovascularized regions are well demonstrated and image noise is held within reasonable limits.

The results are in good accordance with those obtained by the classical bicompartmental analysis of the washout curves established for 25–30 regions per hemisphere and published previously (*8*).

The correlation between adjacent channels is excellent. Because of the high spatial resolution, regions with abnormal blood flow are better localized than in the bicompartmental method, which plots each curve from data recorded in several channels; thus, in the bicompartmental method, the corresponding calculated blood flows for a particular region are mean values, which can sometimes be very misleading.

In order to determine the optimal value of integration time to be used in the function of computed RBF values and their standard deviation, several values were tried. [The integrated images (H_{max}) were always centered over the momental initial peak values]. A value of 10 sec is a good compromise. Shorter values increased the standard deviation whereas the RBF values remained practically constant. Higher values, e.g., 30 sec, decreased the standard deviation but the RBF values decreased too.

It is evident that the integration time should be as short as possible. In the first place, the initial peak value does not rise at the same time over the whole image. In the second place, an eventual systematic underestimation of the RBF value by using a constant value of integration time (10 sec) for each examination does not affect the RBF distribution and therefore there is no influence on the interpretation of the RBF image even in differential mode.

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