Accuracy of ventricular volume estimation

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SUMMARY Sources of error in the estimation of ventricular volume from CAT scans are discussed and the accuracy of the measurement assessed. Two methods of calculating ventricular volume from an intraventricular injection of radioisotope are described and compared. Finally, the CAT scan and isotope methods are compared and contrasted. The error associated with a single measurement of volume by any of these techniques is between 20% and 30%. In patients with no ventricular catheter there is no choice other than to use CAT scanning, but if intra-ventricular injection is possible this method offers a potentially more accurate volume determination because of his higher signal-to-noise ratio.

Computerised tomographic (CAT) scanning pro-vides a new method of assessing ventricular size. Because this technique is atraumatic (unless anaesthesia is required) it is likely to be used much more freely than previous methods, and in par-ticular repeated examinations in the same patient will be feasible. This makes it important to know the reliability of assessments of ventricular size based on CAT scans, and in particular to know the significance of changes in size between different examinations on the same patient (Gawler *et al.*, 1976; Roberts *et al.*, 1976; Penn *et al.*, 1978).

Estimates of ventricular size are important in diagnosis, in deciding about the need to intervene surgically (in particular by ventricular shunting procedures), and in judging the efficacy of treat-ment designed to deal with hydrocephalus. The range of changes in ventricular size encountered in clinical practice has led most people to feel that decisions can be taken without an exact measure of ventricular size. While this may be so, there are likely to be an increasing number of circumstances in which precise measurements will be of value. In normal pressure hydrocephalus it has been sug-gested that the results of shunting do not correlate with a reduction in ventricular size (Shenkin *et al.*, 1975; Jacobs and Kinkel, 1976), but the accuracy of the estimation of size must be carefully considered in studies of this nature before drawing such conclusions.

Monitoring of intracranial pressure has been applied in a limited number of conditions. Where mean intracranial pressure is not grossly increased, other parameters have been sought to quantify the degree of abnormality. The presence of B waves and the width of intracranial pressure pulse have been suggested to be of prognostic significance in patients with normal pressure hydrocephalus (Symon and Dorsch, 1975; Belloni *et al.*, 1976). Attempts have been made to measure indices of brain compliance (Brock *et al.*, 1975; Avezaat *et al.*, 1976; Marmarou *et al.*, 1976; Szewczykowski *et al.*, 1976; Sullivan *et al.*, 1978). The clinical significance of a certain value for compliance in large ventricles compared with that in small ventricles is, however, not clear (Miller *et al.*, 1975), and so ventricular volume is a parameter which should be considered when assessing the results of intracranial pressure measurement.

Ventricular CSF metabolites such as HVA and 5HIAA have been estimated in various neuro-logical disorders, and conclusions drawn without any reference to the ventricular volume of distribu-tion. It cannot be assumed that this volume re-mains constant in any patient and certainly not in patients who have been shunted (Maira *et al.*, 1975). Hence variations in, for example, HVA concentration may result from variations in ventricular size or CSF bulk flow and absorption and not necessarily from changes in dopamine turnover.

The ventricular system is usually delineated by CAT scans, and the ventricular volume may be measured by summing the ventricular areas in all

sections of the brain. In the first part of this paper we discuss the magnitude of the errors associated with such measurements.

Ventricular volume may also be measured by following the passage of a radioactive isotope injected into the ventricles. Two methods of doing this are described, and the estimates of size are compared with the CAT scan estimates. Finally, radioisotope ventriculography enables the clearance rate from the ventricles of a radioactive tracer to be calculated. In order to convert this to a bulk flow rate it is necessary to know the volume of distribution of the tracer.

Ventricular volume measurement by the CAT scan method

Ventricular volume estimation from a CAT brain scan depends on a threshold being chosen below which the Hounsfield number is taken to represent the CSF. If A is the area of the ith section then the volume is simply

$$V = T \sum_{\text{All } i} A_i$$

where T is the thickness of each section.

The principal source of error lies in the determination of threshold. Cerebrospinal fluid should have an EMI number of 0 or 1 Hounsfield units and brain tissue between 20 and 40 Hounsfield units. Previously Gawler et al. (1976) used a threshold of 22 Hounsfield units, and Roberts et al.

(1976) used a threshold of 18 Hounsfield units. We have computed the ventricular volume on 10 patients at a variety of thresholds by manual calculation from the line printer output. Figure 1 shows the results of the measurements normalised to 100% at a threshold of 10 units. Clearly, the volume estimation is dependent on the threshold selected.

Figure 2 illustrates the results of some measurements of contrast sensitivity in which Hounsfield number is plotted against density for EMI scanner phantoms with skull thicknesses of 8 mm and 11 mm. As variations in skull thickness of several millimetres do occur from patient to patient, or even from slice to slice within the same patient, an error of 1 or 2 Hounsfield units could quite easily occur. Other factors, such as the presence of surrounding oedema or haematoma, and basic instability, can also affect the validity of a threshold value. An uncertainty of 2 or 3 Hounsfield units could be present in the threshold determination, and Fig. 1 shows that this corresponds with a volume change of between 20 and 30%.

Ventricular volume measurement by the injection of a radioactive isotope

Radioisotope ventriculography may be used to study CSF dynamics in patients with hydrocephalus (De Blanc et al., 1972; Di Chiro et al., 1976; Cabanes and Vazquez, 1977). Typically 50 μCi of ^{99m}Tc DTPA or of ^{111}In DTPA are injected into the lateral ventricle via a ventricular catheter. Diethylenetriaminepentacetic acid (DTPA) has a higher molecular weight (600) than pertechnetate
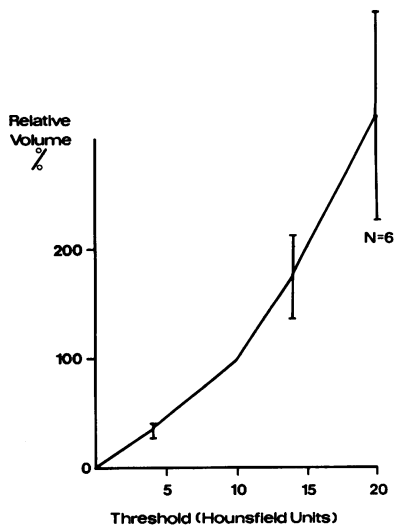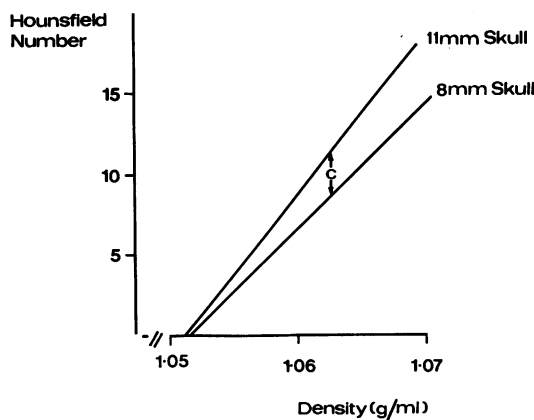

Fig. 1 *Dependence of the calculated ventricular volume on cut-off threshold. Volumes were computed using threshold values of 4, 10, 14, and 20 and normalised 100% at a threshold of 10 Hounsfield units. N=10 unless otherwise stated.*

Fig. 2 *EMI scanner contrast sensitivity calibration graph showing Hounsfield Number as a function of density as measured on our EMI Mark II scanner using phantoms with different skull thickness.*

(163) and, therefore, has the advantage that peri-ventricular diffusion takes place more slowly. Formerly human serum albumin (molecular weight 70000) was used but this has been abandoned because of an adverse reaction in some patients. Unless there is blockage at the foramen of Monro the radioisotope will mix uniformly throughout both lateral ventricles within a few minutes. Clearance from the ventricular system to the subarachnoid space takes several hours and so, if images are taken using a gamma camera at about 10 minutes after injection, the ventricles can be clearly delineated with very little blurring caused by isotope in the subarachnoid space. Images taken at two hours demonstrate a "double density" pattern; a denser inner zone corresponding to the ventricles and a less dense outer zone corresponding to isotope in brain surrounding the ventricles (Milhorat and Hammock, 1971). It is important not to exaggerate this problem: blurring of the ventricular image is caused mainly by limitations of collimator design (Griffith and Staddon, 1973). Therefore, from the point of view of ventricular volume measurement it is important that images taken fairly soon after injection of the radioisotope are used.

Ventricular volume may be estimated from two perpendicular images using the following methods.

1. In the method of Akerman *et al.* (1972) vertex and anterior images of the brain are used to find various ventricular dimensions. If A is the anterior/posterior distance, B is the height, and C1 and C2 the width of each lateral ventricle, volume is then computed using the empirical equation V=K1. A. B. (C1+C2) where K1 is an empirical constant. This method takes no account of variations in shape and the method described below is an attempt to overcome this disadvantage.

2. The gamma camera image taken from the vertex projection can be divided into a number of matrix elements, M, each with counts C_i ($1 \leqslant i < M$). Neglecting tissue absorption, the total volume is proportional to the sum of the counts in each element multiplied by the cross-sectional area of each element—that is

$$V \propto K2 \sum_{i=1}^{M} C_i$$

where K2 is the area of each matrix element. The example in Fig. 3 illustrates this.

The anterior image enables an absolute determination of volume to be made by calibrating C max in terms of the ventricular height, b. Thus

$$V = K2 \frac{b}{C_{max}} \sum_{i=1}^{M} C_i$$
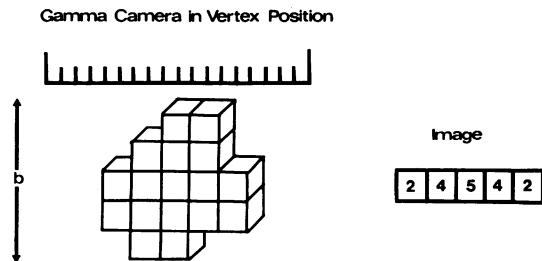
Gamma Camera in Vertex Position

Fig. 3 *Schematic illustration of how "depth" information can be obtained from a gamma camera scintiphoto. If tracer is distributed homogeneously, and if absorption of gamma radiation is insignificant, the count rate per pixel is proportional to depth. Another view from the lateral or frontal projection enables this to be calculated.*

As there is not an appreciable difference in gamma ray attenuation between brain tissue and ventricular CSF, absorption will produce an error only if there is a significant asymmetry (Fig. 4). In this extreme situation shape C, which has the greatest part of its bulk furthest away from the gamma camera, is underestimated in volume by about 11%, conversely shape B has its volume overestimated. As ventricular shape will be much less asymmetrical than this, the error caused by asymmetry should be small and typically not more than 5%.

These methods of computation make different assumptions regarding the distribution of isotope. Method 1 has the advantage of being unaffected by inhomogeneity of mixing so long as some tracer is mixed throughout the ventricles, and it is independent of the absorption of gamma rays within the ventricles. It has the disadvantage of relying on an empirical equation which does not vary with ventricular shape. With both methods a cut-off threshold has to be determined because of
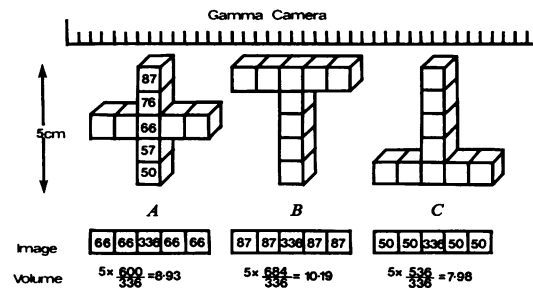

Fig. 4 *Illustration of the effect of tissue absorption of gamma rays in an extreme situation. The absorption figures are typical of those of ⁹⁹ᵐTc (140 keV gamma rays) in tissue.*

image blurring. A sharp edge when imaged appears rounded, and so threshold has to be chosen. For a rectangular organ, threshold would be 50%. To determine the thresholds for methods 1 and 2, a ventricular phantom was constructed by modelling plastic around a plasticine model using average dimensions of the human ventricular system (Last and Tompsett, 1953). Some radioisotope was then introduced into the phantom, and it was imaged in the conventional way. The results indicated that a threshold value of 40% is suitable along with values for the empirical constants of K1=0.53 and K2=0.76.

COMPARISON OF THE RADIOISOTOPE METHODS
Eight sets of ventriculograms of patients being investigated for normal pressure hydrocephalus were used. An isovolumetric injection technique was employed in all cases. Two sterile syringes were connected to a three-way tap, one empty and one containing 50 μCi or ^{99m}Tc DTPA in 1 ml of saline: 2.0 ml of CSF was withdrawn into the empty syringe, the injectate was then introduced and flushed in with 1.0 ml of the withdrawn CSF. No isotope was left in the catheter with this technique. Scintiphotos taken, beginning at 5 and 15 minutes, indicated that mixing was completed after five minutes. Figure 5 illustrates the results of volume estimation by methods 1 and 2.

There are two types of error associated with these methods, E1, a computational error determined by the accuracy of measurement of A, B, and C, and E2, an error which is governed by inherent inaccuracies in the method such as the
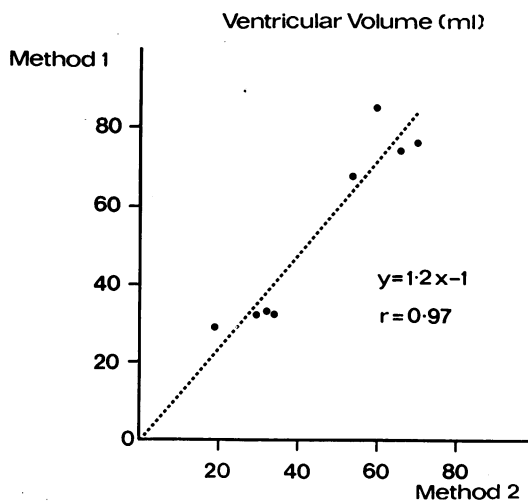
blurring effect produced on some of the narrow CSF connecting pathways. The error in A, B, and C can be estimated to be around 8%, 16%, and 8% respectively for normal ventricles making a computational E1 in V of around 20%. This will be greatly reduced for large ventricles. As the shape of the ventricular system does not generally vary a great deal from person to person, and as the method was calibrated against the realistic phantom, the error E2 should not be much more than an estimated 10%, making the overall error of the method somewhere between 25% and 30%.

The main source of error, E1, in method 2 is again in the measurement of B. The total accuracy of this method can be assessed experimentally by comparing the volume obtained from the vertex projection with that obtained using the anterior projection. The mean ventricular volume of the patients studied was 37 ml and the standard deviation of the difference between paired measurements was 7.3 ml, giving a total error of 20%.

COMPARISON OF THE RADIOISOTOPE AND CAT SCAN METHODS
Eight of the patients investigated above also had a CAT scan. Using the criterion that Hounsfield numbers less than 8 represent CSF, ventricular volume estimation was performed on these scans. Figure 6 shows a comparison of these results with corresponding radioactive isotope results.
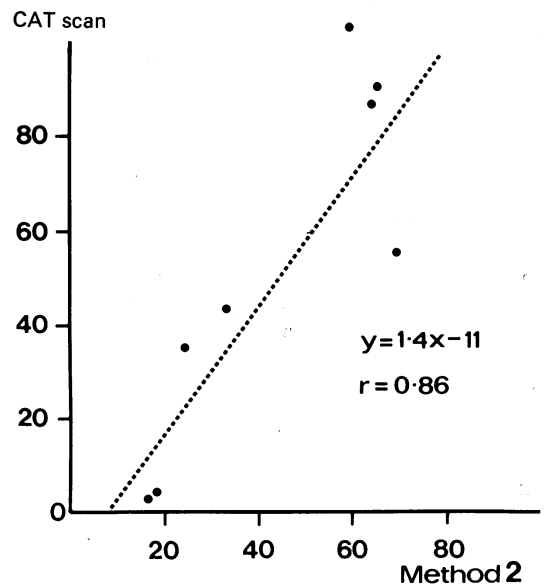

Fig. 6   *Correlation between ventricular volume computed on eight patients from a CAT scan and radioisotope method 2. A threshold of 8 was used for the CAT scan estimation.*

Fig. 5   *Correlation between ventricular volumes computed on eight patients by methods 1 and 2.*

Discussion and conclusions

The radioactive isotope determination was performed using a poor resolution gamma camera (NE MkIV) with an intrinsic full width at half maximum of 16 mm, and the data were stored in a PDP-12 computer using 64×64 matrix. A better resolution gamma camera and a finer matrix would greatly increase the accuracy of both these methods.

It is important with these methods to ensure that mixing is complete. The presence of a focal hot spot which takes 30 to 40 minutes to disperse indicates delayed mixing, and if this is the case the later views should be used in the volume estimation.

The CAT scan method has a better resolution but poorer signal-to-noise ratio compared with the radioactive isotope methods, and it is very sensitive to changes in threshold. It is obviously the method of choice for patients with no ventricular catheter. Penn *et al.* (1978) calculated the error in ventricular volume estimation to be 16% based on phantom measurements. They found a similar critical dependence of computed volume on Hounsfield number threshold to that illustrated by us in Fig. 1. Our estimation of a possible error of between 20% and 30% is for scan data on patients where uncertainties about skull thickness or presence of surrounding oedema have to be coupled with the fundamental inaccuracies of the scanner which can be measured from phantom scans. Pneumoencephalography does not provide a flawless independent estimate because the introduction of air into the ventricles changes ventricular size (Gawler *et al.*, 1976). General anaesthesia confounds the problem still further (Moseley *et al.*, 1977).

In conclusion, the error associated with a single measurement by any of the methods in this study is between 20% and 30% but the radioisotope methods, with a fine resolution gamma camera, offer a potentially more accurate determination of volume because of the higher signal-to-noise ratio.

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