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Mass volume measurement in severe head injury: accuracy and feasibility of two pragmatic methods

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Abstract
Objective—To assess the clinical feasibility and the accuracy of two pragmatic methods in comparison with a conventional computer based method of measurement of masses from CT.
Methods—Nineteen CT scans of 11 patients with severe head injury, showing 34 traumatic lesions, were examined. The volume of every lesion was digitally measured, then a panel of three examiners independently repeated the measurement using the ellipsoid and the Cavalieri method in random order.
Results—All the lesions were identified by all the readers and the mean volume measured by each examiner differed by less than 1.5 ml. The average reading time for each scan was 4 minutes for the ellipsoid and 7 minutes for the Cavalieri method. The average volume of the lesions was 34.2 (SD 35) ml with the digital system, and 38.4 (SD 41) ml and 34.8 (SD 36) ml for the ellipsoid and the Cavalieri readings respectively. The average difference between the applied technique and the digital system was 0.57 (SD 9.99) ml for the Cavalieri direct estimator and 0.20 (SD 15.48) ml for the ellipsoid method. The 95% confidence interval for this difference fell between –2.75 and 3.89 ml for the Cavalieri, and between –4.94 and 5.35 ml for the ellipsoid method. There were 19 lesions >25 ml; the ellipsoid method identified 16 of them, whereas 17 were classified with the Cavalieri method. When considering individual lesions rather than the average volume, discrepancies were detected with both methods. The ellipsoid method was less precise, especially when extracerebral lesions were measured.
Conclusions—Both pragmatic methods are inferior to computer based reading, which is the choice when accurate volume estimation is necessary. However, if a digital volumetric determination of the lesions using a CT computer is not possible, the two pragmatic methods offer an alternative.

Keywords: head injury; computed tomography; mass lesions

Due to the physical properties of the dura and the skull, every acute increase of volume in the intracranial space may lead to intracranial hypertension.1 This is especially relevant after traumatic brain injury, when the development of post-traumatic intracranial masses is the most dangerous complication.2

In head injury, the volume of masses has been identified as one of the prognostic factors,3 and a CT grading system accepted worldwide incorporates volume measurements.3

When a cerebral contusion or an extra-axial collection increases, ample variations in volume are easily detected without meticulous measurement. When subtle changes develop over time, on the other hand, the precision provided by more scientific measurement techniques offers a more valuable basis for clinical decision making.

The calculation of a given area, and the reconstruction of a delimited volume, are quite feasible with modern CT apparatus, especially when a dedicated workstation is part of the machinery. Unfortunately, volume determinations are seldom performed during routine CT readings, although the digital measurement of the lesions is the most accurate system available today. Finally, digital measurement proves impossible or cumbersome when multicentre trials are conducted, and central reading of CT is planned.

There is, therefore, a need for pragmatic methods of volume measurement on the CT printouts, provided that those methods are accurate and feasible.

The ellipsoid method (EM) was developed to calculate the volume of arterovenous malformations.4 It is based on the concept that the volume of an ellipsoid is about one half the volume of the parallelepiped into which it is placed. By measuring three diameters of a given lesion in the arterial phase of an angiogram, a parallelepiped is reconstructed, and its volume, divided in half, is close to the real volume of the malformation. By extending this geometrical concept from angiography to CT scan, calculation of space occupying lesions becomes possible (fig 1 A).

More recently, the Cavalieri direct estimator (CDE) has been introduced.5 It breaks down the lesion on CT into a corresponding number of points, through special grids; the volume of a lesion appearing on the scan is the product of the sum of the points that fall on the lesion, the area associated with each point, and the distance between scan slices (fig 1 B). The grid can be constructed by photocopying a template provided in the original article6 or by preparing a uniformly spaced point grid (by computer or by hand) to be copied onto an overhead transparency.
As volume measurement is clinically important, but rarely performed in the neuroradiological practice, a posteriori methods, feasible even outside the neuroradiology department, may be useful or necessary. We have therefore assessed the performances and the feasibility of two pragmatic methods (the EM and the CDE) in measuring the volume of mass lesions in cases of patients with severe head injury.

**Materials and methods**

Eleven patients with severe head injury admitted to the neuroscience intensive care unit of a university hospital in 1997 were studied. They were eight men and three women, mean age 53 (SD 19) years, with a median Glasgow coma score after resuscitation of 6. Each patient underwent CT at admission, and repeated controls thereafter. Among the scans of these patients, 19 containing mass lesions were selected. A lesion was defined as a hyperdense or mixed (hyperdense and hypodense) area.

Each scan was digitally processed (CT Scan Pace, General Electric, Maryland, USA) to determine the volume of every lesion. Such measurements were taken by a neuroradiologist, who traced every lesion on the screen and calculated the area and volume of interest. That was accepted as the reference gold standard. The results of these measurements were not disclosed to the panel of examiners.

Three members of the intensive care unit staff were trained in the identification and measurement of areas and volumes on the CT slices by using the two pragmatic methods. As part of the training, the examiners performed collective readings of several scans of patients not participating in the study, and repeated measurements of lesions using the CDE and EM under the guidance of a neuroradiologist. Grids for the CDE were prepared and provided to the examiners. Relevant references in the literature were reviewed. After this training period, which required about 2 weeks, the 19 CT scans and appropriate examination forms were submitted to each panellist separately. The CDE and EM were used in a random order.

Both the volumes measured in each scan and the reading time for each method were recorded in the forms. The data forms were then collected, summarised, and compared with the gold standard.

To assess the agreement between the two pragmatic methods and the gold standard the statistical method devised by Bland and Altman was used. A two way analysis of variance (ANOVA) was used for measuring the interobserver variability. The Pearson \( \chi^2 \) test with Yates continuity correction was used for comparing percentages.

**Results**

The 19 CT scans studied comprised 23 contusions/lacerations, 10 subdural haematomas, and four extradural haematomas. The range of the lesions directly computed at the CT scan varied from 3 ml to 124 ml; the sum of all lesions produced a total volume of 1260.65 ml, with an average volume for every lesion of 34.23 (SD 35.88) ml.

**Reader Agreement and Readings**

The readings performed by the three examiners led to consistent measurements. The results of their calculations were very close; the mean volume measured by each examiner differed by <1.5 ml. The ANOVA analysis confirmed this finding, excluding any significant difference among the readers in the use of both methods. All 37 lesions were identified by all readers, providing 222 pragmatic measurements to be compared with the gold standard.

The measurements calculated by the three readers with each method for every lesion were averaged; this average represented the volume calculated with the method. The range of the lesions measured with the EM varied from 0.9
Intracerebral versus extracerebral lesions

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<td>23</td>
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Figure 2 The y axis shows the difference between the volume read with the CDE and the volume measured with the computerised method. This difference is plotted against the x axis, in which the gold standard is reported. The zero line represents the line of equality, corresponding to a perfect agreement between the two methods of measurement. Each point indicates one or more lesions detected on the CT scan. All values are in ml.

Figure 3 The y axis shows the difference between the volume read with the EM and the volume measured with the computerised method. This difference is plotted against the x axis, in which the gold standard is reported. The zero line represents the line of equality, corresponding to a perfect agreement between the two methods of measurement. Each point indicates one or more lesions detected at the CT scan. All values are in ml.
Discussion

The volume of intracranial lesions, and its change over time, is of obvious interest in the diagnosis and management of patients with head injury. Specific features of space occupying lesions, including their volume, are associated with the outcome of patients with traumatic brain injury.\(^6\)

Based on data from the traumatic coma data bank,\(^5\) Marshall et al\(^6\) showed that the existence of specific findings from CT, including the presence of masses exceeding 25 ml, was associated with increasing degrees of mortality and morbidity. This scale is now widely used both in clinical practice and in the scientific literature on head injury. Interestingly, this scale requires the measurement of the volume of intracranial lesions, as the threshold of 25 ml is part of the grading.

In some clinical trials recently performed on head injury, a central reading of the CT scan was carried out,\(^1\) and intracranial volume measurements performed.\(^2\)

There are clinical problems, such as the evolution of a cortical contusion, that require volume measurement. The overall mass effect, which is considered for clinical management, depends on the size of a given lesion and on the associated swelling and oedema as well, but the size of the lesion itself is crucial.

For these reasons an accurate estimate or, possibly, the measurement of the volume of cerebral masses has become an integral part of the treatment and of the classification of severe head injury.

Unfortunately, the determination of the volume of masses is not performed as an element of the routine reading of CT scans. In a recent multicentre study on head injury\(^3\) involving 18 neurotraumatological centres, all 18 centres claimed to have used the Marshall scale, but the volume of lesions was seldom measured in one centre, and never measured in the other 17 (personal unpublished data).

The data collected in this study show that both pragmatic methods are on average acceptably precise when performed by readers who underwent a short training period. Accuracy was achieved by all readers, as no difference was found among them in their calculation of the volume. The systematic error of the pragmatic methods was <1 ml, and the mean volume of all lesions measured with the EM and CDE was very close to the volume measured digitally. When considering individual lesions rather than the average volume, however, discrepancies were detected with both methods and some discrepancies were relevant especially with the EM.

The CDE is more accurate than the EM. That is proved by the Bland and Altman technique. It is recommended whenever accuracy of measurement is crucial for possible therapeutic decisions.