Short Communication

Intracranial Area: A Validated Method for Estimating Intracranial Volume

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ABSTRACT

Background and Purpose. Controlling for intracranial volume is crucial in magnetic resonance studies of changes in brain volumes. However, full intracranial volume measurement requires prolonged scanning and analysis, and simple, validated methods for intracranial volume estimation are lacking. The authors developed and evaluated a method of estimating intracranial volume using a single mid-sagittal slice, the intracranial cross-sectional area. *Methods*. Forty men aged 65-70 had whole skull magnetic resonance scans at 1.9 T, with slice thickness of 1.5 mm (no interslice gap). Intracranial cross-sectional area was traced in the midline sagittal slice of the 3-view localizer. Intracranial volume was measured using every slice. Ten intracranial cross-sectional area measurements were tested for interrater reliability. *Results*. Intracranial cross-sectional area and intracranial volume correlated highly ($r = .88$, $P < .0001$). A modified Bland-Altman plot showed good agreement between intracranial cross-sectional area and intracranial volume. The intraclass correlation (an indicator of reliability) for intracranial cross-sectional area was $r = .976$ ($P < .005$). *Conclusions*. The rapid and simple technique of intracranial cross-sectional area measurement provides a valid and reliable estimate of intracranial volume.

Key words: Intracranial area, intracranial volume, hippocampus, atrophy, dementia.

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Measuring intracranial volume (ICV) is important in MR studies of changes in regional brain volumes, for example, the hippocampus, in diverse conditions to correct for differences in overall brain size.[1] However, the analysis is very time-consuming, computing intensive, and requires considerable expertise. Published methods of estimating ICV have generally not been assessed for validity or reliability.[2,3] We developed and evaluated a simple method of estimating intracranial volume using a single mid-sagittal slice, the intracranial cross-sectional area (ICA).

Methods

Subjects

Forty men aged 65-70 were drawn randomly from a cohort of 100 scanned in a normal aging study.[4] The protocol was approved by the Lothian Health Ethics Committee. Informed consent was obtained.

Magnetic Resonance Imaging and Analysis

Brain imaging was performed in an Elscint Prestige MR scanner (now GE, Haifa) operating at 1.9 T. Structural image acquisition followed a 3-view localizer and consisted

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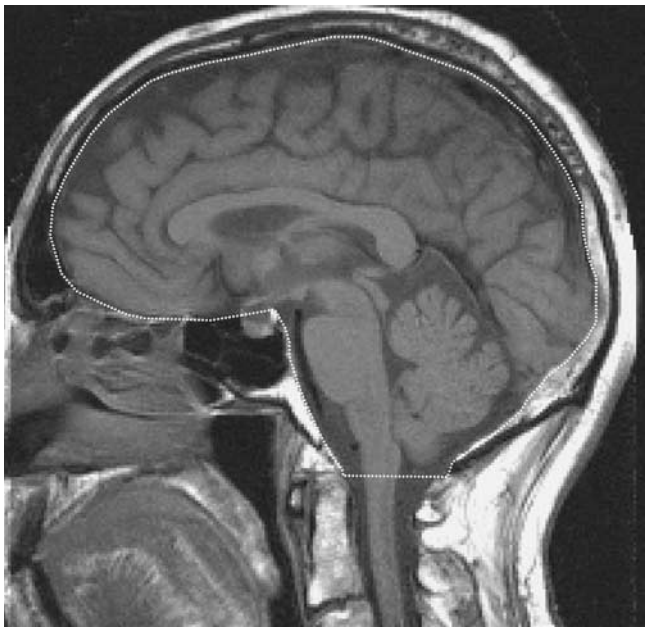

Fig 1. Determination of intracranial cross-sectional area.

Table 1. Descriptive Statistics for Intracranial Volume and Intracranial Area in 40 Individuals Aged 65 to 70 Years[1]

	Mean	Maximum	Minimum	Standard Deviation
Intracranial volume, mm^3	1,600,237	1,964,610	1,386,468	124,494.3
Intracranial cross-sectional area, mm^2 (ICA)	15,963	19,095	14,004	1096.1

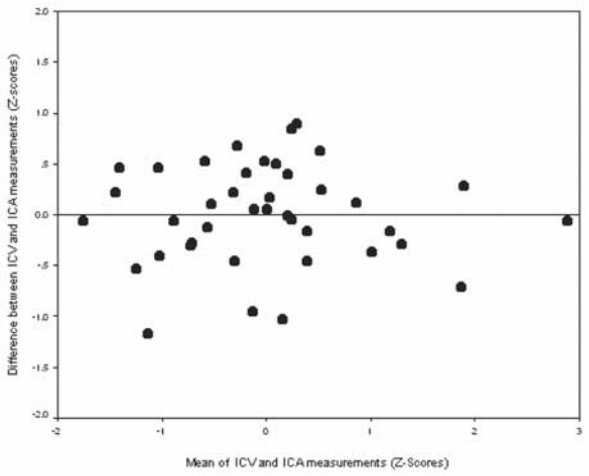

Fig 2. Modified Bland-Altman plot of *z* scores of intracranial volume and intracranial cross-sectional area.

of a coronal T1-weighted 3-dimensional gradient echo sequence covering the entire brain and skull (TE = 9.254, TR = 28.5, tip angle = 25°, slice thickness = 1.5 mm [no interslice gap], 18 cm field of view, matrix = 180 × 180). The images were transferred to a network of Sun workstations (Sun Microsystems, Mountain View, CA) for image analysis using Analyze™ software (Mayo Clinic, Rochester, MN).

Intracranial Cross-Sectional Area

This was traced manually in the sagittal slice of the 3-view localizer, which was placed in the midline. This measurement involved manually tracing around the inner table of the cranial vault, along the floor of the frontal fossa, continuing this line across the pituitary fossa to the dorsum sella. Tracing continued down the posterior surface of the clivus, and the area was completed by a horizontal line joining the anterior and posterior rims of the foramen magnum (Fig 1).

Intracranial Volume

To reduce the amount of manual editing, the volume sequence was first edited by imposing an intensity threshold to separate the intracranial volume (all subdural structures including venous sinuses, arteries, spaces occupied by cerebrospinal fluid, roots of cranial nerves as well as the brain) from the skull. This threshold was set at the intensity that corresponded to the interface between the meninges and the signal void caused by the dense bone of the inner table of the cranium. Manual editing was used to define the intracranial volume in areas where the automatic threshold was inadequate, for example, where the bone had a trabeculated medulla giving rise to high signal and where cranial nerves passed through the skull. In these areas, a limit was drawn that continued the line of the adjacent bone to separate the intracranial structures from the skull. As in the intracranial area measurements, the pituitary gland was excluded from measurements by drawing a line manually across the superior-most points of the clinoid processes. The caudal limit of the intracranial volume was a line drawn horizontally at the level of the foramen magnum between the antero-superior edge of the posterior rim and the posterosuperior edge of the anterior rim. All measurements were made starting anteriorly on the first slice in which the meninges appeared and continued posteriorly in every slice until the last traces of the meninges disappeared.

Measurement of the 40 ICV and ICA scans was carried out by a research fellow (K.J.F.) at different times for each measurement and blind to each measurement. Scans were not identified by the individual's name. Descriptive

statistics are shown in Table 1. Five ICV measurements were assessed for intrarater reliability: the intraclass correlation was $r = .989$ ($P < .0001$). The Pearson correlation between ICV and ICA was $r = .88$ ($P < .0001$, N = 40). A modified Bland-Altman plot (using z scores of ICA and ICV instead of the absolute values) showing good agreement between the 2 measures across the range of measurements is shown in Figure 2. The regression equation is ICV = 5479.8 + (99.9 * ICA). The reliability of the ICA measurement was carried out in a subset of 10 scans analyzed by KJF and CLE. The intraclass correlation coefficient for ICA was $r = .976$ ($P < .005$), indicating a high interrater reliability.

Discussion

ICA was highly correlated with ICV, and the interrater reliability for ICA was high. ICA is a good estimate of ICV. This is consistent with other work showing that depending on the shape of the structure and orientation of the imaging section in relation to its largest cross-sectional axis, the measurement of a cross-sectional area can be a good estimate of the volume of the whole structure.[5] There are several advantages to using the ICA. It can be obtained from a single midline sagittal slice in a commonly performed sequence (eg, the localizer used to position the individual in the scanner), thereby reducing scanning time. Measurement of ICV requires multiple slices and the whole skull to be included.[6] Depending on the scanner and software, it may not be possible to increase the number of slices sufficiently to acquire whole brain coverage without using thicker slices and so losing image detail in subregions. The ICA method is therefore useful in circumstances where images of only certain brain regions, such as the hippocampus, are examined. Although we evaluated it on MR, it could possibly even be applied on CT using the lateral scout view. Finally, the method requires far less analysis time and training, making it suitable for studies in which there are large numbers of individuals to assess. Disadvantages of this method include problems associated with all 2D methods: inability to take account of different head shapes and reliance on the position of the plane of view. Further work will help to establish this method's reliability and validity in the context of controlling for intracranial volume in the measurement of brain subregions. Other work might also examine the reliability and validity of the ICA method in other populations.

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