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Estimating postoperative skull defect volume from CT images using the ABC method

Furen Xiao[a,b], I-Jen Chiang[a,c], Thomas Mon-Hsian Hsieh[a], Ke-Chun Huang[a], Yi-Hsin Tsai[a,b], Jau-Min Wong[a], Hsien-Wei Ting[d], Chun-Chih Liao[a,d,*]

[a] Institute of Biomedical Engineering, National Taiwan University, Taipei, Taiwan
[b] Institute of Clinical Neuroscience, National Taiwan University Hospital, Taipei, Taiwan
[c] Graduate Institute of Medical Informatics, Taipei Medical University, Taipei, Taiwan
[d] Department of Neurosurgery, Taipei Hospital, Taipei, Taiwan

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ABSTRACT

Objectives: Surgeons often perform decompressive craniectomy to alleviate a medically-refractory increase of intracranial pressure. The frequency of this type of surgery is on the rise. The goal of this study is to develop a simple formula for clinicians to estimate the volume of the skull defect, based on postoperative computed tomography (CT) studies.
Methods: We collected thirty sets of postoperative CT images from patients undergoing craniectomy. We measured the skull defect volume by computer-assisted volumetric analysis (V_m) and our own ABC technique (V_{abc}). We then compared the volumes measured by these two methods.
Results: The V_m ranged from 3.2 to 76.4 mL, with a mean of 38.9 mL. The V_{abc} ranged from 3.8 to 71.5 mL, with a mean of 38.5 mL. The absolute differences between V_{abc} and V_m ranged from 0.05 to 17.5 mL (mean: 3.8 ± 4.2). There was no statistically significant difference between V_{abc} and V_m ($p = 0.961$). The correlation coefficient between V_{abc} and V_m was 0.969. In linear regression analysis, the slope was 1.00086 and the intercept was −0.0035 mL ($r^2 = 0.939$). The residual was 5.7 mL.
Conclusion: We confirmed that the ABC technique is a simple and accurate method for estimating skull defect volume, and we recommend routine application of this formula for all decompressive craniectomies.

1. Introduction

The number of patients who undergo decompressive craniectomy (DC) to alleviate medically-refractory increase of intracranial pressure is rising. Such intercranial pressure may be caused by trauma, stroke, or other pathologies [1–3], and the primary goal of DC is to create additional space to accommodate the swollen brain. Numerous clinical practice guidelines mention DC as an option for these conditions [4–6]. As a result, some reports describe the postoperative change of the brain and the intracranial space [7,8]. However, none of these previous studies addressed the volumetry of skull defects. Surgeons should regard the volume of the skull defect as one of the most important quantitative parameters that can be used to evaluate the decompressive effort.

With the widespread use of picture archiving and communication systems (PACS), we can calculate the volume of a skull defect by direct volumetric subtraction using imaging software, just as we would do for any other volume of interest. But this golden standard has been applied only on rare clinical occasions [4], probably because it is a relatively time-consuming process and a robust approximation is usually good enough for clinical practice. Another difficulty for direct volumetry of a skull defect is that the missing skull is actually invisible in the image. To perform precise volumetry, one must apply image registration techniques to pre- and post-operative images, which are usually impossible using common PACS client software.

The "ellipsoid method" ("ABC/2" method) was originally developed to calculate the volume of arteriovenous malformations [9]. This technique has gained wide clinical acceptance for estimating volumes of interest, including various type of intracranial hematomas [4,10,11]. However, the ellipsoid method cannot be used directly to estimate the volume of skull defect after a craniectomy, because the shape of such a defect is usually far from ellipsoid. Similarly simple methods for volume estimation of the

* Corresponding author at: Department of Neurosurgery, 127 Su-Yuan Road, Hsin-Chuang, Taipei County, 242, Taiwan. Tel.: +886 2 2276 5566, fax: +886 2 2998 8028.
E-mail address: d95548001@ntu.edu.tw (C.-C. Liao).

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skull defect should exist, but have not been described in the literature.

The goal of this study is to develop a simple formula that can be used conveniently by clinicians, including neurosurgeons, neurologists and neuro-radiologists, to estimate the volume of the skull defect, based on routine non-volumetric brain CT studies.

2. Materials and methods

We collected thirty sets of non-volumetric postoperative CT images from patients undergoing craniectomy in a regional hospital in northern Taiwan, during the 48-month period from July 2006 to June 2010. All brain CT examinations were done according to a standard protocol concordant with clinical practice guidelines [4]. The time interval for craniectomy and CT studies ranged from one day to three months (median: twelve days). The images were downloaded from the PACS and saved to a personal computer for further analysis.

The locations of the skull defects were supratentorial in 26 of the patients and infratentorial in four. Among the 26 patients with supratentorial skull defects, twelve patients had DCs after subdural hematomas (SDHs) had been evacuated; six patients had DCs after traumatic intracerebral hematomas (ICHs) had been evacuated; and three patients had DCs after spontaneous ICHs of the basal ganglion had been evacuated. The reasons for supratentorial skull removal in the remaining five patients were as follows: open comminuted fracture prohibiting primary repair of the cranium (two patients); late infection of the artificial skull plate made of poly(methyl methacrylate) (one patient); epidural hematoma with brain swelling (one patient); and recurrent glioma with brain swelling (one patient).

We routinely perform unilateral paramedian suboccipital craniectomy as a part of the emergency management for patients with the cerebellar mass and signs of brain stem compression. Among the four patients included in our subjects who had infratentorial skull defects, three underwent craniectomies for spontaneous ICH and one for cerebellar metastasis of lung cancer.

Three board-certified neurosurgeons used our proprietary software to perform computer-assisted volumetric measurement of all skull defects [12]. Because only soft tissues remained at the sites of skull defects, the human experts delineated the contour of the missing part based on the shape of the corresponding contralateral skull region. We were then able to calculate the volume of the skull defect using the modified technique of Hier et al. [13]. A detailed methodology of volume measurement can be found in our previous work [12].

Yet another board-certified neurosurgeon estimated the volume of the skull defect using the ABC technique. The ABC technique was adapted for this purpose as illustrated in Fig. 1. This technique is similar to the ABC/2 technique used for estimating the volume of cresentic subdural hematoma [14].

After the slice with the largest dimension of skull defect was identified, the linear distance between corners of the outer table of skull defect was used to determine the length (*A*). The thickness (*B*) was measured as the maximum thickness of the defect from the inner table of the skull to the outer table, presumed to be perpendicular to the length. Again, the measurement is made on the corresponding skull region at the contralateral part of the skull. The height (*C*) was determined by summing the inter-slice distance on which full-thickness skull defect was visible on the CT images.

To obtain the volume, the product $A \times B \times C$ was calculated. There was no additional coefficient such as 1/2 in estimating ICH/SDH.

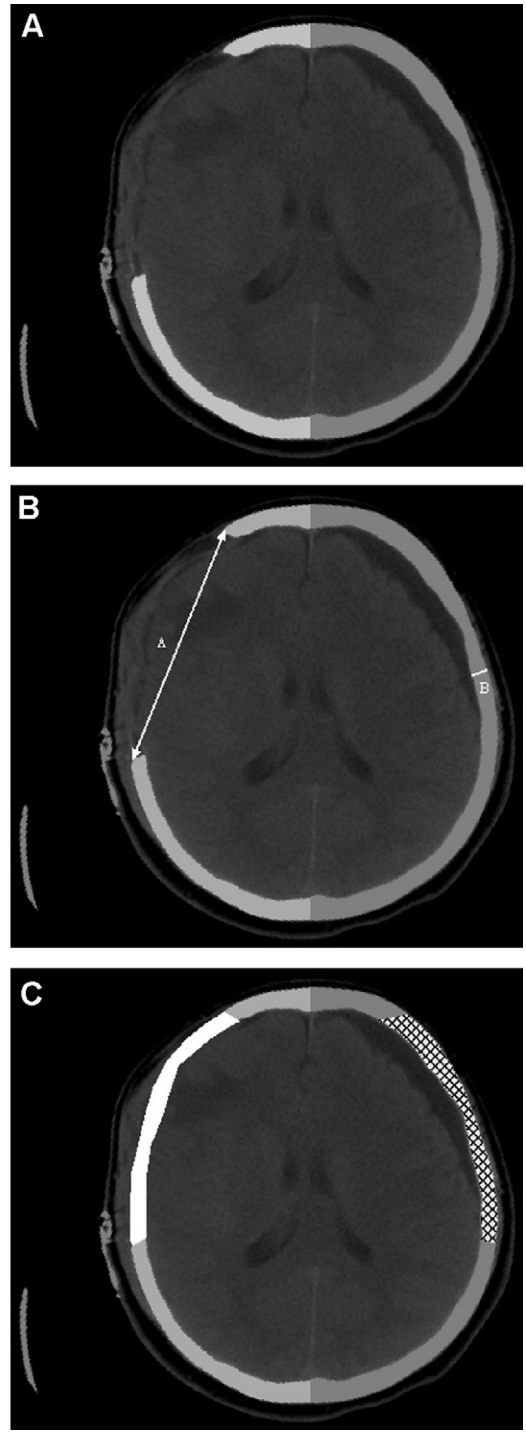

Fig. 1. An example of estimating the volume of the postoperative skull defect on brain CT. (A) The original image. The approximate symmetry of the skull is demonstrated by using two different gray levels for each half. (B) Measurement of *A* and *B* in the ABC technique. The linear distance between corners of the skull defect was used to determine the length (*A*). The thickness (*B*) was measured on the corresponding contralateral skull region as the maximum thickness presumably perpendicular to the length (*A*). (C) Computer-assisted volumetry using the bilateral symmetry of the skull. The manually-traced skull defect region, shown in bright white, is based on the corresponding region of the contralateral intact skull, shown as the cross-hatched area.

3. Results

The volumes of the thirty skull defects in our sample, as calculated by computer-assisted manual volumetry (V_m), ranged from 3.2 to 76.4 mL, with a mean of 38.9 ± 23.1 mL. Pearson's correlation