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New CT measurements to assess decompression after hemicraniectomy: A two-center reliability study

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ABSTRACT

Objectives: To test the reliability of three simplified measurements made after decompressive hemicraniectomy (DHC) for malignant hemispheric infarction on computed tomography (CT) scan.
Patients and methods: We defined new simple methods to measure the thickness of the soft tissues overlying the craniectomy defect and the extent of infarction beyond the anterior and posterior craniectomy edges on post-DHC CT. Multiple raters independently made the three new CT measurements in 49 patients from two institutions. The Intraclass Correlation Coefficient (ICC) compared the raters for interrater agreements (reliability).
Results: Between two raters at Augusta University Medical Center, each measuring 21 CT scans, the ICC coefficient point estimates were good to excellent (0.83 – 0.92). Among four raters at University of Virginia Medical Center, with three raters measuring each of 28 CT scans, the ICC coefficient point estimates were good to excellent (0.87 – 0.95).
Conclusions: The proposed simple methods to obtain three additional CT measurements after DHC in malignant hemispheric infarction have good to excellent reliability in two independent patient samples. The clinical usefulness of these measurements should be investigated.

1. Introduction

Decompressive hemicraniectomy (DHC) has been shown to improve functional outcomes in patients with midline brain shift caused by malignant hemispheric infarction [1]. This benefit has been attributed to alleviation of intracranial hypertension and decompression of brain regions adjacent to the infarction, resulting from outward (transcalvarial) brain herniation. However, variability in the DHC technique and neurosurgical complications arising from it may impact the effectiveness of this procedure [2,3]. Post-DHC neuroimaging can objectively assess multiple surgical outcomes that reflect brain decompression, such as outward (transcalvarial) brain herniation, craniectomy size, and change in midline brain shift. Such measurements could be useful in assessing the adequacy of decompression.

We previously defined and tested a simplified approach to measure craniectomy size and brain shifts after DHC [4]. Anterior and posterior infarct extension beyond the DHC edges has also been reported as a likely useful outcome predictor [5].

We hypothesized that in addition to craniectomy size, the soft tissues overlying the craniectomy may to various degrees limit the intended transcalvarial brain herniation and consequently the effectiveness of DHC. The tissues overlying the craniectomy include skin, muscle and connective tissue, dural patches, various amounts of bloody and non-bloody exudates, and occasionally air. Rarely, the resected skull segment is hinged posteriorly and not removed [6]. Thus, in this study we propose three new simple post-DHC CT measurements and test them for reliability among independent raters. If determined reliable, these CT measurements could subsequently be tested for associations with DHC outcomes. Potentially, such observations could optimize the DHC technique.

In our future study on DHC we plan to define surgical effectiveness primarily as < 5 mm midline brain shift on post-DHC CT [7,8] as the dependent variable. Some of the independent variables will include hemicraniectomy size, infarct extension, and thickness of the tissues

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overlying the craniectomy.

2. Patients and methods

2.1. Patient selection

Patients were identified at the two medical centers by a combination of medical records searches and a prospective DHC registry. Based on criteria for our future study on the imaging effectiveness of DHC, we included only patients with ischemic stroke who had head CT scans < 24 h after DHC. We excluded patients with factors that could confound DHC-related brain shifts, such as concomitant resection of necrotic brain or insertion of a cerebral ventricular drain.

At Augusta University Medical Center, we identified 53 patients who had DHC for malignant hemispheric infarction between December 2006 and May 2019. After excluding 10 patients for the prespecified criteria, 43 remained. Two raters, a senior neurology resident (UV) and a stroke neurologist (MS) made the three CT measurements blinded to each other's results. The stroke neurologist measured a random sample of every other patient starting with number one. Thus, paired measurements in 21 patients were available for analysis.

At the University of Virginia Medical Center, we identified 39 patients who had DHC for malignant hemispheric infarction from January 2004 to June 2017. After excluding 11 patients for prespecified criteria, 28 remained. Four raters, a senior undergraduate neuroscience intern (MEG), a senior radiology resident (SA), a neuroradiology fellow (PB), and a neuroradiologist (JD) made the three new measurements of each CT scan blinded to each other's results. Two raters (MEG and JD) measured all 28 scans, one rater (PB) measured scans of patients 1–12, and one rater (SA) measured scans of patients 13-28. Thus, three sets of measurements in 28 patient were available for analysis.

2.2. Image processing

At both institutions, CTs were acquired with 64-row multidetector scanners. The raw data (slice thickness 0.6 mm at Augusta University and 2.5 mm at University of Virginia) were postprocessed on radiology PACS workstations.

We aligned the original CT scans according to our validated simplified method [4]. Two anatomical lines defined the alignments: one, being in the sagittal plane connecting the hard palate and the opisthion (midline posterior border of the foramen magnum); two, being in the coronal plane, connecting the two internal auditory canals. This method standardizes the anatomical CT slice orientation between scans.

2.3. Image measurements

Two senior stroke neurologists (AB, FTN) devised a novel pragmatic method to measure the thickness of the soft tissue barrier to transcalvarial brain herniation overlying the skull defect after DHC. In addition, they defined a method to measure the anterior and posterior extents of the infarcts beyond the craniectomy edges. Fig. 1 illustrates the proposed methods to measure the three distances on post-DHC CT scans. The anterior and posterior extents of infarct measures are based on the findings by Hinduja, et al. [5] This study was approved by the Institutional Review Boards at both institutions.

2.4. Statistical analysis

To assess the reliability of the measurements, we calculated the intraclass correlation coefficients (ICC) using the SPSS statistical package v.25 (SPSS Inc., Chicago, IL, USA). The ICC analysis was based on two-way random effects model, average measurements, with two raters at Augusta University and three raters at University of Virginia. We considered coefficients 0.5-0.74 as indicating moderate reliability, 0.75-0.89 good reliability, and ≥0.90 excellent reliability.

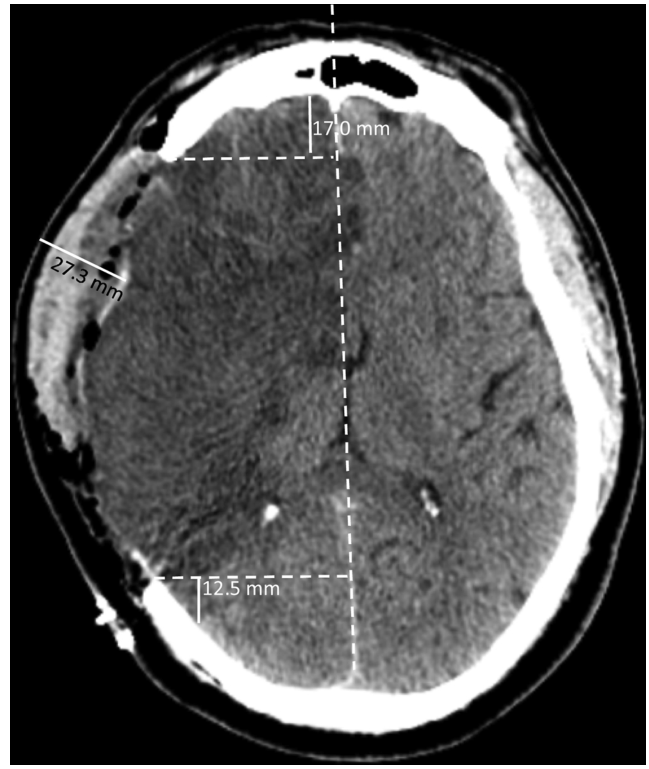

Fig. 1. Examples and definitions of the three new CT measurements after hemicraniectomy.
The solid lines indicate the measurements. The interrupted lines are the skull midline and the perpendicular lines to the craniectomy edges. CT windows are adjusted as needed to optimize visualization of the infarct extensions and the skin. Barrier thickness to transcalvarial herniation is measured from brain surface to skin surface perpendicular to skin surface (27.3 mm); anterior (17.0 mm) and posterior (12.5 mm) extents of infarcts are measured parallel to the midline from the edges of craniectomy to the furthest extents of the infarct, as shown.

3. Results

The 49 patients included from both institutions ranged in age from 11 to 77 years (median 53) and 25 (51 %) were men. The thickness of the soft tissue barrier to transcalvarial herniation median was 23.0 mm (range 5.0–40.2). The anterior extent of infarcts median was 13.0 mm (range 0–41.2). The posterior extent of infarcts median was 11.8 mm (range 0–79.9). Table 1 shows the ICC coefficients with 95 % confidence intervals for interrater reliability for the three measurement. Overall, the correlation estimates range from good (0.83) to excellent (0.95).

4. Discussion

In this study, we propose new and simple methods to measure the thickness of the soft tissue barrier to transcalvarial brain herniation, and anterior and posterior extents of cerebral infarction beyond craniectomy edges, on post-DHC CT scans in patients with malignant hemispheric infarction. These measurements may subsequently be useful in assessing the surgical effectiveness of DHC. We test the reliability of these three measurements. These measurements are relatively simple to make by trained personnel and our findings show good to excellent interrater reliability. The agreement of the results from two independent patient samples suggests likely good generalizability.

The anterior and posterior extents of infarction beyond the craniectomy edges suggest insufficient craniectomy size in relation to stroke size, and may predict worse outcomes. Hinduja et al. analyzed 41

Table 1
Results of interrater reliability analysis for three CT measurements after DHC at two institutions.

	Augusta University Medical Center (N = 21)	University of Virginia Medical Center (N = 28)
Measurement	ICC (95% CI)	ICC (95% CI)
Barrier to transcalvarial herniation	0.92 (0.81–0.97)	0.95 (0.90–0.97)
Anterior extent of infarction	0.83 (0.71–0.96)	0.87 (0.76–0.94)
Posterior extent of infarction	0.89 (0.71–0.96)	0.95 (0.90–0.97)

DHC – decompressive hemicraniectomy; ICC – intraclass correlation coefficient; p values for all correlations are < 0.001.

patients following DHC for malignant hemispheric infarction and found that extension of cerebral infarcts beyond the craniectomy bed was associated with progressive brain herniation [5]. However, the measurement method was not clearly defined or tested for reliability.

The thickness of the tissues overlying the craniectomy may represent a barrier to the intended transcalvarial brain herniation, and should be included in analysis of DHC outcomes. To the best of our knowledge, measuring the thickness of such a barrier has previously not been reported.

In addition to the three measurements tested in this study, size of craniectomy is clearly of interest as a determinant of transcalvarial brain herniation and reduction of midline brain shift. Larger craniectomies after malignant hemispheric infarction have been associated with better clinical outcomes [9], and craniectomy diameter of at least 12 cm has been commonly recommended [3]. In a subsequent study, using our validated method [10], we plan to include hemicraniectomy size as a potential predictor of DHC surgical effectiveness.

A treatable complication of DHC worthy of mention is the trephine syndrome, resulting in a depression over the craniectomy from atmospheric pressure acting against locally reduced brain tissue and intracranial pressure [11]. Neurological worsening is sometimes seen with this complication. The trephine syndrome usually develops several months after DHC, and is successfully treated with cranioplasty.

One limitation in this study is that the relatively simple measurements are unidimensional. Although more involved, volumetric measurements might have been more revealing. It remains to be determined in future prospective studies, if such volumetric measurements will offer a significant advantage. A second limitation is that all three measurements were made at one specified CT level (foramina of Monro), and if made at a different or at multiple levels might have been more informative. The impact of this limitation also remains to be determined. A third limitation is that we made no adjustments for the different tissues within the barriers overlying the craniectomies, which may differentially limit transcalvarial brain herniation independent of the overall barrier thickness.

In future studies we plan to analyze multiple post-DHC measurements in relation to decompression of midline brain herniation in malignant hemispheric infarction. Ultimately, imaging indicators of effective DHC could be tested for prediction of clinical outcomes. This may eventually lead to optimization of the DHC technique.

Declaration of Competing Interest

None of the authors has any financial interests to disclose.

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