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Automated assessment of midline shift in head injury patients

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ABSTRACT

Objectives: Midline shift (MLS) is an important quantitative feature for evaluating severity of brain compression by various pathologies, including traumatic intracranial hematomas. In this study, we sought to determine the accuracy and the prognostic value of our computer algorithm that automatically measures the MLS of the brain on computed tomography (CT) images in patients with head injury.

Patients and methods: Modelling the deformed midline into three segments, we had designed an algorithm to estimate the MLS automatically. We retrospectively applied our algorithm to the initial CT images of 53 patients with head injury to determine the automated MLS (aMLS) and validated it against that measured by human (hMLS). Both measurements were separately used to predict the neurological outcome of the patients.

Results: The hMLS ranged from 0 to 30 mm. It was greater than 5 mm in images of 17 patients (32%). In 49 images (92%), the difference between hMLS and aMLS was <1 mm. To detect MLS >5 mm, our algorithm achieved sensitivity of 94% and specificity of 100%. For mortality prediction, aMLS was no worse than hMLS.

Conclusion: In summary, automated MLS was accurate and predicted outcome as well as that measured manually. This approach might be useful in constructing a fully automated computer-assisted diagnosis system.

1. Introduction

Shortly after the invention of computed tomography (CT), its value on the diagnosis of traumatic brain injury was well demonstrated. Analysis of Traumatic Coma Data Bank data revealed midline shift (MLS) more than 15 mm as an important outcome predictor regardless of the clinical condition [1]. MLS is one indicator of brain compression by intracranial mass, or "mass effect", which is usually a better predictor of outcome than the size of the mass itself [2]. Quantification studies were performed by Ropper [3] to detect the earliest CT changes associated with depression of consciousness as soon as the intracranial lesion was detected. He concluded that horizontal displacement of the pineal body of 0–3 mm from the midline was associated with alertness, 3–4 mm with drowsiness, 6–8.5 mm with stupor, and 8–13 mm with coma. The "dose-dependent" relationship between MLS and neurological condition as well as clinical outcome seemed to be established. According to current guidelines for the surgical management of traumatic brain injury [4], MLS of more than 5 mm is an indication for operation in various intracranial lesions.

We had previously developed an algorithm to determine the deformed midline from head CT [5,6]. Our algorithm worked well even with large MLS. There were also other authors attempted to do this with limited success. Yuh et al. [7] had achieved good sensitivity and specificity on detecting MLS >5 mm. However, most of their subjects (96%) had relatively small MLS (<5 mm).

Our previous publication [6] mainly focused on the technical details of midline shift recognition. In addition to confirming the accuracy of our algorithm in determination of MLS in patients with head injury, this study investigated the clinical implication of our approach. We correlated the images with the patients' outcome to see if the automated MLS determined by our algorithm is comparable to that determined by human experts for outcome prediction.

2. Materials and methods

In our previous publication [6], there were 86 consecutive patients admitted to the neurosurgical intensive care unit of Taipei Hospital, Taiwan, from July 2003 to June 2004. Head injuries were the reason for admission in 54 patients, and all patients except one of them had head CT in the emergency department and the ini-

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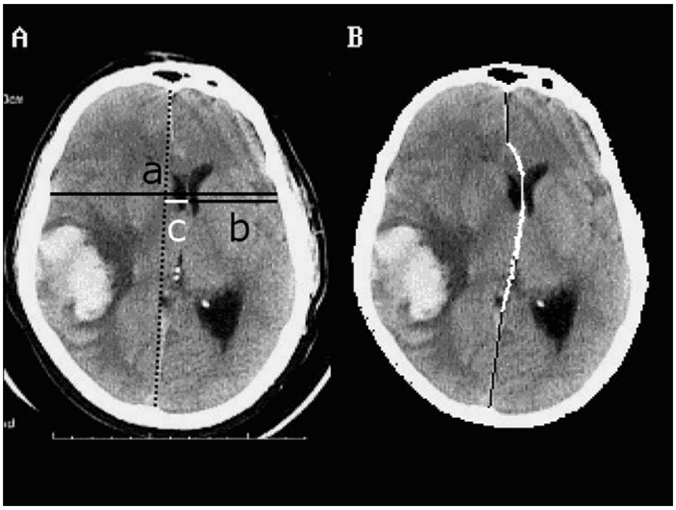

Fig. 1. Assessment of midline shift (MLS). (A) Although determination of MLS by first measuring the width of the intracranial space ($c = a/2 - b$) was suggested by the guideline, many neurosurgeons measured it by first drawing the ideal midline (dotted line). (B) Our computational model for the deformed midline included a quadratic Bézier curve between two line segments.

tial images were used for analysis. The remaining 53 images were downloaded to a personal computer for processing. Demographic data and initial Glasgow Coma Scale (GCS) of these patients, history of surgical procedures, as well as neurological outcome in Glasgow Outcome Scale (GOS) 3 months after injury, were also collected.

The clinical management of these patients adhered the second edition of guidelines for severe traumatic brain injury if possible [8]. Surgical management was considered in patients with stable hemodynamics and GCS less than or equal to 8 or midline shift more than 5 mm. Decompressive craniectomy with duroplasty was usually performed unless brain swelling was minimal as in some cases with epidural hematoma. During operation, the epidural and subdural hematomas were evacuated whenever encountered. However, we did not touch intraparenchymal hemorrhage unless it was quite large (i.e. more than 50 mL in volume). The subdural transducer device for intracranial pressure (ICP) monitor was usually inserted during operation, and if it was available, we tried to keep ICP >30 mmHg and cerebral perfusion pressure (CPP) greater than 60 mmHg. Besides the routine intensive care for hemodynamics, the methods for ICP and CPP management included head elevation, mild hyperventilation, sedatives with muscle relaxants, mannitol, aggressive volume replacement with vasopressors and another operation if necessary.

After the images were downloaded from the picture archiving and communication system (PACS) to a personal computer, manual measurement of MLS by human (hMLS) was performed on the computer screen by a board-certified neurosurgeon. The measurements took place at the level of foramen of Monroe as suggested by the guideline [4]. However, the method of measurement was slightly different from the guideline by first drawing the ideal midline (Fig. 1A). The neurosurgeon also measured the dimensions of major hematomas and calculated the volumes using the "ellipsoid method" described in the guideline. In short, if measured diameters of the hematoma are referred as length (A), width (B) and height (C), the volume can be estimated as ABC/2 [9]. We will later refer it as the estimated hematoma volume (EHV) in our article, in order to differentiate it from volumetric measurement, which was rarely applied during clinical practice.

The algorithm to determine MLS automatically had been detailed elsewhere [5,6]. Basically, our method tries to identify the deformed midline on the CT slice by decomposing it into three segments: the anterior and the posterior straight segments representing parts of the cerebral falx separating two cerebral hemispheres, and the central curved segment formed by a quadratic Bézier curve, representing the intervening soft brain tissue (Fig. 1B). The deformed midline was obtained by minimizing the summed square of the differences across all midline points, applying a genetic algorithm. The automated MLS (aMLS) was considered good if its difference from hMLS was within 1 mm. Otherwise, it was classified as poor.

We then set up simple models to predict outcome of the patient using either hMLS or aMLS. For comparison, models using the EHV were also established. We evaluated the performance of these models by the receiver operating characteristic (ROC) curve. The area under the ROC curve (AUC) was used to quantify performance of each model. For a randomly chosen pair of patients, the AUC represents the probability that a patient who dies has a higher predictive probability for mortality. The higher the AUC, the better the model discriminates.

2.1. Statistical analyses

Analyses were performed using R, an open-source statistical language [10]. Correlation was obtained with Pearson's method if both variables were interval (e.g. lengths and volumes) and Spearman's method if either is ordinal variables (e.g. GCS and GOS). Areas under ROC curves were compared using DeLong's nonparametric approach [11]. Probability (p) values of <0.05 were considered statistically significant.

3. Results

3.1. Clinical and radiological features

The clinical and radiological features of these patients were summarized in Table 1. There were 37 males and 16 females. Their ages ranged from 11 to 97 years (mean: 47 years). According to the GCS at the emergency room, the injury is mild in two patients (4%), moderate in 31 (58%), and severe in 20 (38%). The most common intracranial pathology was subdural hematoma (34%) and intracerebral hemorrhage (21%). There were six patients whose images showed no major hemorrhage. The estimated volume of main hematoma, if existed, ranged from 0.45 to 364.1 mL (median: 39.93 mL, $n = 38$).

Fifteen patients (28%) underwent operations, most of whom were victims of traffic collisions (Table 1). Operations were indicated in six patients, but were not carried out due to profound shock of the patient or refusal of the family. The neurological outcome was available in 51 of these patients. Twenty-two patients (43%) had good recovery while 17 (33%) died within 3 months.

3.2. Manually measured MLS and its determinants

Manual measurement of MLS (hMLS) was used as the gold standard for MLS. The distribution of hMLS was shown in Fig. 2A. The measurements ranged from 0 to 30 mm. The median and mean of hMLS were 2.75 and 5.1 mm. The MLS was >5 mm in 17 patients (32%) and was >10 mm in 10 patients (19%).

As expected, MLS correlated with every dimension of hematoma, and, more importantly, the estimated hematoma volume (EHV, $p < 0.001$). In addition, we found that patients with younger age and SDH tend to have larger MLS using multivariate analysis ($p = 0.005$ and $p = 0.011$, respectively). The initial GCS also correlated with both the EHV ($p < 0.001$) and the hMLS ($p = 0.002$), and patients undergoing surgery had larger MLS ($p = 0.009$).