Reappraisal of Pediatric Diastatic Skull Fractures in the 3-Dimensional CT Era: Clinical Characteristics and Comparison of Diagnostic Accuracy of Simple Skull X-Ray, 2-Dimensional CT, and 3-Dimensional CT

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■ BACKGROUND: **Diastatic skull fractures (DSFs) in children are difficult to detect in skull radiographs before they develop into growing skull fractures; therefore, little information is available on this topic. However, recent advances in 3-dimensional (3D) computed tomography (CT) imaging technology have enabled more accurate diagnoses of almost all forms of skull fracture. The present study was undertaken to document the clinical characteristics of DSFs in children and to determine whether 3D CT enhances diagnostic accuracy.**

■ METHODS: **Two hundred and ninety-two children younger than 12 years with skull fractures underwent simple skull radiography, 2-dimensional (2D) CT, and 3DCT. Results were compared with respect to fracture type, location, associated lesions, and accuracy of diagnosis.**

■ RESULTS: **DSFs were diagnosed in 44 (15.7%) of children with skull fractures. Twenty-two patients had DSFs only, and the other 22 had DSFs combined with compound or mixed skull fractures. The most common fracture locations were the occipitomastoid (25%) and lambdoid (15.9%). Accompanying lesions consisted of subgaleal hemorrhages (42/44), epidural hemorrhages (32/44), pneumocephalus (17/44), and subdural hemorrhages (3/44). A total of 17 surgical procedures were performed on 15 of the 44 patients. Fourteen and 19 patients were confirmed to have DSFs by skull radiography and 2D CT, respectively, but 3D CT detected DSFs in 43 of the 44 children (*$P < 0.001$*).**

■ CONCLUSION: **3D CT was found to be markedly superior to skull radiography or 2D CT for detecting DSFs. This finding indicates that 3D CT should be used routinely rather than 2D CT for the assessment of pediatric head trauma.**

INTRODUCTION

Skull fractures are one of the most common trauma injuries among children, comprising 2%–16% of all head injuries and 11% of injuries in children younger than 2 years.[1-3] Approximately 15%–50% of skull fractures are associated with intracranial injuries, such as intracranial hemorrhage, contusion, cerebrospinal fluid leakage, or vessel injury, and 40%–100% of intracranial injuries in children are accompanied by cranial fractures.[1,4,5] Hence, it has been suggested that skull fractures in children are associated with significant mortality and morbidity resulting from intracranial injury, and that accurate diagnosis is critical.[6]

Diastatic skull fractures (DSFs) involve the suture line either partially or wholly, and they are more frequently encountered in children than in adults.[7] In the past, DSFs have been diagnosed in children with simple skull radiography, but because sutural ossification is incomplete in children, physiologic diastasis can make the diagnosis of DSF problematic.[7,8] Because of these diagnostic difficulties, many authors have stressed the clinical importance of accompanied growing skull fractures that increased the DSF diagnostic rate in children. Without growing skull fractures, little information regarding DSFs is available in the literature regarding the prevalence, associated intracranial injuries, and

Key words
- CT
- Diagnosis
- Diastatic fracture
- Head trauma
- Pediatric
- Skull fracture

Abbreviations and Acronyms
2D: 2-Dimensional
3D: 3-Dimensional
CT: Computed tomography
DSF: Diastatic skull fracture

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clinical course, along with older diagnostic methods such as simple skull radiography.[9-11]

Recent technological advances in 3-dimensional (3D) computed tomography (CT) have led to the use of 3D CT rather than, or in combination with or instead of, 2-dimensional (2D) CT or simple skull radiography for the evaluation of all cranial fractures for all ages, especially for children because 3D CT can provide more accurate assessment of linear skull fractures.[4,6,12,13] However, literature on the use of 3D CT for the diagnosis of DSF is limited to a single report by Kim et al.,[8] who described 15 cases of DSF. Somewhat surprisingly, no clinical reports have addressed this subject to date. We retrospectively studied the relationship between the clinical characteristics of 44 children with DSF and simple skull radiography, 2D CT, and 3D CT findings. In addition, we compared the diagnostic accuracies of 3D CT, simple skull radiography, 2D CT, and simple skull radiography plus 2DCT.

MATERIALS AND METHODS

Study Population

Simple skull radiography, 2D CT, and 3D CT for 347 pediatric patients younger than 12 years who visited our institute for head trauma during the 9-year period from May 1, 2005, to April 30, 2014, were examined retrospectively. Of the 347 patients, 292 had various types of skull fractures as follows: linear fracture in 191 patients (65.41%), diastatic fractures in 22 patients (7.53%), depression fractures in 21 patients (7.19%), basal skull fractures in 5 patients (1.71%), burst fractures in 2 patients (0.68%), a greenstick fracture in 1 patient (0.34%), and combinations of the aforementioned fractures in 50 patients (17.12%; Table 1). Nontraumatic skull fractures with other etiologies were excluded. Forty-four patients with DSF (22 DSF only and 22 DSF plus another fractures) were included in this study.

Table 1. Type of Skull Fracture in 292 Pediatric Head Trauma Patients

Type of Skull Fracture	Number of Patients	%
Linear	191	65.41
Diastatic only	22	7.53
Depressed	21	7.19
Basal	5	1.71
Burst	2	0.68
Greenstick	1	0.34
Mixed*	50	17.12
Diastatic	22	
Linear	44	
Depressed	20	
Basal	2	
Burst	3	
Total	292	100

*Multiple or compound skull fractures.

Image Protocol and Analysis

The diagnostic criteria used for DSF as determined with simple skull radiography, 2D CT, and 3D CT were as described previously: (1) suture margins separated by at least 1.5 mm at two separate points measuring 2.5 cm apart or greater, and (2) asymmetric sutural widening of 1 mm or greater in the affected area.[7] The 44 pediatric patients had objective findings such as scalp swelling, bruising, and lacerations caused by head trauma within the previous 3 days. Patients with bilateral suture widening attributed to increased intracranial pressure were excluded.

All CT data were acquired using a 64-detector row CT scanner (Brilliance 64; Philips Medical Systems, Best, the Netherlands) using the following protocol: 120 kVp; 100 mAs; collimation, 16 $\times$ 0.625; rotation time, 0.6 seconds; pitch, 0.683; section thickness, 4 mm; and reconstruction increment, 0.5 mm (1.0 mm). The 3D reconstruction was performed on the scanner's workstation using commercially available software (Extended Brilliance Workstation; Philips Medical System, Best, Netherlands) and a reconstruction increment of 0.5 mm over 1.0 mm, and a window level of 120 with a length of 255 mm. All simple skull radiographic, 2D CT, and 3D CT images were reviewed by a pediatric neuroradiologist and a pediatric neurosurgeon.

For analysis, cranial fractures as determined by simple skull radiography, 2D CT, and 3D CT were classified by type and location. To determine the clinical characteristics of pediatric DSFs, we also studied the presence and treatment of associated lesions, such as subgaleal hematoma, pneumocephalus, intracranial hemorrhage, brain swelling, and subdural fluid collection. This retrospective study protocol was approved by our University Hospital Institutional Review Board (AJIRB-MED-MDB-17-115).

Statistical Analysis

Fisher exact test and the McNemar test were used to compare diagnostic efficiencies using 95% confidence intervals. Kappa analysis was performed to determine interobserver and intermodality agreements. Kappa values were divided into intervals of 0.2 from 0.0 to 1.0, and agreements were classified as follows; poor ($\kappa < 0$), slight ($\kappa = 0.01-0.20$), fair ($\kappa = 0.21-0.40$), moderate ($\kappa = 0.41-0.60$), substantial ($\kappa = 0.61-0.80$), and almost perfect ($\kappa = 0.81-0.99$).

RESULTS

Incidence and Clinical Characteristics of DSF

For the 292 children with cranial fractures, DSF was diagnosed in 44 of them (15.7%). Of these 44 patients, 31 were male, and the mean overall age was 64.4 $\pm$ 37.3 months. Eleven patients had a simple DSF, 11 patients had multiple DSFs, and the remaining 22 patients had DSFs plus multiple compound fractures (Figures 1–3). The most common location of DSFs was the occipitomastoid suture (20/44) followed by the lambdoid suture (15/44; Table 2).

The most common lesions associated with DSF in were subgaleal hemorrhage (42/44), epidural hemorrhage (32/44), pneumocephalus (17/44), and subdural hemorrhage (3/44). Fifteen of