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ORIGINAL ARTICLE – OPEN ACCESS

Can three-dimensional Reformatted Computed Tomography Scans be Useful to Avoid Misdiagnoses of Skull Fractures in Pediatric Emergency Cases?

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ABSTRACT

Objective: To investigate whether three-dimensional (3-D) reformatted cranial computed tomography (CT) scans may contribute to the avoidance of misdiagnosis of skull fractures in pediatric emergency cases.

Materials and Methods: This cross-sectional medical chart review was carried out in the pediatric emergency department of a tertiary care center. Data were derived from pediatric age group patients having head trauma patients whose conventional CT images were obtained at initial admission. Demographic, clinical, and radiological data, the location of the fracture, and possible causes of misdiagnoses were recorded.

Results: This study included 27 children (21 males and six females). The average age was 41.92±43.25 (range, 1 to 137) months. The most common etiology for admission to the hospital was fall from height (85.2%). The fractures were detected on the parietal (n=12, 44.4%), frontal (n=7, 25.9%), occipital (n=7, 25.9%) and temporal (n=1, 3.7%) bones. In 12 cases (44.4%), skull fracture could not be detected at their initial admission. Five of these 12 cases were consulted to the radiologist, and diagnosis could not be established even by the radiologist. In 15 pediatric head trauma patients (55.6%), the skull fracture was confirmed by the radiologist. In two cases with an initial failure of diagnosis, 3-D reconstruction allowed the identification of fractures.

Conclusion: The findings obtained in this study suggest that 3-D reconstruction of CT scans may increase the accuracy of diagnosis for pediatric skull fractures.

Keywords: Skull fractures, craniocerebral trauma, child, diagnosis, tomography

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INTRODUCTION

Skull fractures occur at a rate of 2–11% in children exposed to head trauma (1). Pediatric craniofacial fractures display oblique fracture patterns, while typical adult fractures exhibit patterns described by LeFort. Pediatric craniofacial fractures are under higher risk of growing fractures (2). With increasing age, the proportion of craniofacial fractures in all pediatric fractures tends to increase (3). Different types of traumatic mechanisms may be responsible for pediatric skull fractures (4). Even though CT is the primary diagnostic imaging modality, it may be unnecessary in following pediatric skull fractures, particularly in asymptomatic patients, to omit cumulative added radiation exposure and increased cost (5). Early recognition and appropriate management of skull fracture in the pediatric population is associated with good outcome and may prevent unwanted morbidity and mortality (6).

In routine clinical practice, head computerized tomography (CT) is a sensitive measure to diagnose post-traumatic skull fractures (7). In some circumstances, two dimensional (2-D) CT images cannot be sufficient to demonstrate subtle or linear fractures in the axial plane on images (8). Skull fractures may occur in linear, depressed, diastatic, or basilar (skull base) fashion, and linear fractures constitute approximately 75% of all fractures (7, 8). Intracranial injury is a significant cause of mortality and morbidity in children (9). Since a skull fracture may be a critical indicator of an intracranial injury; timely and accurate establishment of the diagnosis is crucial (8, 9).

This study aimed to assess whether the 3-D reconstruction of head CT images may add valuable information for the diagnosis of skull fractures in pediatric emergency cases.

MATERIALS and METHODS

Study Design

This cross-sectional medical chart review was carried out using the records of the patients having trauma who had admitted to the pediatric emergency department of our tertiary care center. Following the approval of the local institutional review board (2019/09-45), we conducted a retrospective review of the hospital records of the Dokuz Eylül University Hospital. The approval of the Dokuz Eylul University Hospital had been obtained before

Table 1. Axial head computerized tomography protocol for pediatric trauma patients admitting to the emergency service (4)

Element	Parameters
Tube parameters	Baby 0–2 yrs: Tube voltage 100 kV, tube current 100 mA, rotation time 0.5 sec
	Child 3–5 yrs: Tube voltage 120 kV, tube current 150 mA, rotation time 0.5 sec
	Child 6–12 yrs: Tube voltage 120 kV, tube current 150 mA, rotation time 0.75 sec
Dose modulation	Child software package (Toshiba Aquilion), dose enabled
Reconstructions	Transverse orientation, 0.75 mm section thickness, 0.5 mm reconstruction interval, bone reconstruction kernel
Field of view (cm)	18–24 cm

conducting this study. Head CT studies were reviewed from our pediatric radiology database covering the time between January 1, 2017, and December 31, 2017.

Patients between 0 to 12 years of age presented in our pediatric hospital during the study period were considered eligible for this study. The radiology reports of standard clinical head CT examinations were reviewed to identify pediatric patients with skull fractures. Patients with initial head CT demonstrating skull fractures involving the frontal, parietal, occipital, and temporal bones were included, whereas patients with fractures involving the skull base and maxillofacial bones were excluded since these fractures are usually more complicated and may necessitate a different approach.

Computerized Tomography Imaging

Computerized tomography images were obtained using Toshiba Aquillion Prime (160-channel) devices. All images were obtained at a single center and stored by the picture archive and communication system (PACS).

The examinations were achieved on a 160–detector system (Toshiba Aquillion Prime) using our institutional pediatric CT protocol, as described in the relevant literature (Table 1) (10). Image reconstruction was performed using a workstation. All examinations were stored on the PACS system.

Image Analysis

All CT examinations were independently evaluated by the pediatric emergency physician, and some of the cases were consulted to the radiologists for ruling out any skull fractures. These two readers made independent evaluations. The 2-D and 3-D CT image data sets were reviewed in bone windows.

In every assessment, the readers sought the presence or absence of any skull fracture, and if a fracture was detected, the involved bones were described. The readers either confirmed the presence of a definite fracture or ruled out the fracture.

RESULTS

This study included 27 children (21 males and 6 females). Their age was between 41.92±43.25 (range, 1 to 137) months. The etiology for admission to the hospital was fall from height (n=23, 85.2%), traffic accident (n=3, 11.1%), and other trauma (n=1, 3.7%). The fractures were detected on the parietal (n=12, 44.4%), frontal (n=7, 25.9%), occipital (n=7, 25.9%) and temporal (n=1, 3.7%) bones. The side of involvement was right (n=14, 51.9%), left (n=10, 37.0%), midline (n=2, 7.4%) and bilateral (n=1, 3.7%). An overview our baseline descriptive data is presented in Table 2.

Table 2. An overview of baseline descriptive in our series (age is expressed in months)

No	Gender	Age	Side	Bone involvement	Etiology
1	M	5	R	Parietal	Fall from height
2	M	35	R	Occipital	Fall from height
3	F	12	R	Occipital	Fall from height
4	M	135	R	Frontal	Traffic accident
5	F	3	L	Parietal	Fall from height
6	M	43	L	Frontal	Fall from height
7	M	40	L	Frontal	Fall from height
8	M	112	L	Temporal	Fall from height
9	F	5	R	Parietal	Fall from height
10	M	94	L	Parietal	Fall from height
11	M	21	R	Frontal	Fall from height
12	M	3	L	Parietal	Fall from height
13	M	1	R	Parietal	Fall from height
14	M	137	M	Occipital	Fall from height
15	M	36	R	Parietal	Fall from height
16	F	8	R	Parietal	Fall from height
17	F	5	R	Parietal	Trauma
18	F	56	R	Frontal	Fall from height
19	M	21	R	Parietal	Fall from height
20	M	99	R	Frontal	Traffic accident
21	M	79	L	Parietal	Traffic accident
22	M	14	B	Parietal	Fall from height
23	M	4	R	Parietal	Fall from height
24	M	36	M	Occipital	Fall from height
25	M	11	R	Parietal	Fall from height
26	M	19	L	Frontal	Fall from height
27	M	101	L	Occipital	Fall from height

F: Female; M: Male; R: Right; L: Left; M: Midline; B: Bilateral

In 12 cases (44.4%), skull fracture could not be detected at their initial admission to the pediatric emergency service. Of these 12 patients, one patient (8.3%) has been hospitalized due to subdural hemorrhage, while 11 cases (91.7%) had been discharged from the pediatric emergency service. Five (41.6%) out of these 12

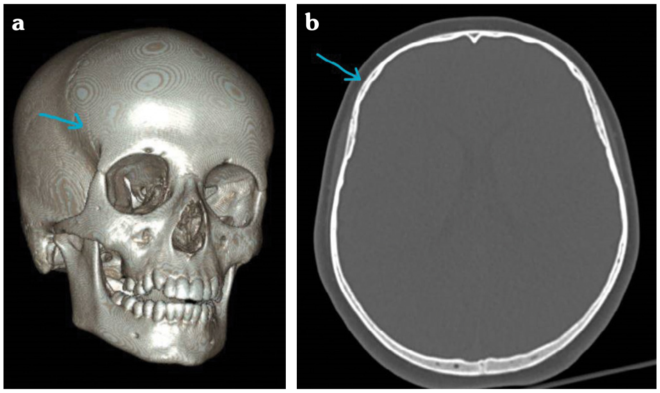

Figure 1. (a) 3-D reconstructed view of the cranial fracture in the temporofrontal region. (b) Fracture line which can be easily skipped unless an axial CT scan is carefully evaluated

cases with an initial failure of diagnosis for skull fracture had been consulted to the radiologist, and diagnosis could not be established even by the evaluation of the radiologist. Only two (16.6%) out of these five cases had 3-D reformatted CT sections. One (8.3%) of the 12 cases with a failed diagnosis of skull fracture involving the temporal bone reported a hearing loss on the left ear.

In 15 pediatric head trauma patients (55.6%), the skull fracture was confirmed by the radiologist. The total number of patients consulted to the radiologist for assessment of the CT scans was 20. The clinicians on call who examine the patients do not routinely ask for 3-D reformatted views. The 3-D reformatted CT views were sought and evaluated by radiologists only.

Eight out of the 15 patients (53.3%) with an initial diagnosis of skull fractures had 3-D reconstructions. On the other hand, nine (75%) out of 12 patients whose skull fractures could not be detected initially had 3-D reconstructions of their head CT images. In two cases, with initial failure of skull fracture diagnosis, 3-D reconstruction allowed the identification of fractures that could not be viewed due to motion artifact or other suspected fractures.

Figures 1a and b demonstrate cranial fractures detected using 3-D reconstructed CT views. A comparative evaluation of these scans was performed using axial sections. On axial views, thin fractures may be readily skipped due to low radiation doses administered during CT scans.

DISCUSSION

In the present study, we aimed to investigate whether 3-D reformatted cranial CT scans may contribute to the avoidance of misdiagnosis of skull fractures in pediatric emergency cases. Our results indicated that 3-D reconstruction of CT scans increases the accuracy of diagnosis for pediatric skull fractures.

The algorithm for routine CT imaging of pediatric head trauma patients involves axial 2-D images and 2-D multiplanar reformatted images in coronal and sagittal planes. Multidetector CT may provide data set from which 2-D, multiplanar, and 3-D reconstructions can be derived (11). The high sensitivity of volume-rendered 3-D CT in detecting skull fractures was emphasized in a previous report (12). The 3-D data set can be achieved through simple post-processing techniques right after the acquisition of 2-D images. 3-D reconstruction is an important diagnostic modality without additional cost, time, or radiation exposure. The time interval needed for the preparation of the 3-D data set by the CT technician is short, and it can be prepared in another workstation, thereby without interference with the routine workflow (8). Orman et al. (8) studied the potential additional value of 3-D CT diagnosing skull fractures in pediatric emergency cases. They recommended the routine use of 3-D reconstruction for imaging after head trauma in pediatric cases.

Various computer algorithms can be used to produce 3-D reconstructions of CT image data sets. In previous publications, the utility and value of 3-D reconstruction of head CT images have been shown (10, 13). Our findings were consistent with the findings obtained by Orman et al. (8), supporting that the use of 2-D and 3-D CT in conjunction amplifies the sensitivity in the diagnosis of skull fractures in all children. 3-D CT does not bring about an additional cost, time for scanning, or radiation exposure. Therefore, it provides an additional valuable diagnostic measure for trainees and clinicians in the routine imaging of pediatric head trauma. A close collaboration between pediatricians and radiologists is essential to avoid misdiagnosis in pediatric head trauma patients. Moreover, increased awareness of the utility of 3-D reconstruction of head CT images in cases suspected for skull fractures may improve the diagnostic accuracy in the evaluation of pediatric head trauma patients. They may have an additional benefit for the interpretation of fractures by discrimination from sutures.

Children with suspected head trauma often apply to the emergency departments after hours when pediatric radiologists are available. Thus, pediatric emergency department physicians will read skull radiological images and determine the management protocol. In this setting, interpretation of the images can be challenging due to superimposed suture lines, fissures, vascular grooves, and Wormian bones (14, 15). These structures may lead to misdiagnosis of subtle skull fractures, and children may develop more severe clinical pictures for intracranial injury (15). Previous reports indicated that the accuracy of pediatric emergency physicians was limited for interpretation of skull radiographs, particularly in infants and young children (16, 17). Notably, the use of 3-D reconstructions of CT scans was found to increase the sensitivity of diagnosing linear skull fractures in children (8).

A head CT is supposed to identify both fractures and intracranial injury sufficiently. CT with 3-D reconstruction may be more practical to interpret when a radiologist's consultation is unavailable (18).

Head trauma and skull fracture bring about specific problems regarding diagnosis and treatment. A minor linear fracture may stay unnoticed at CT scan until it causes CSF leak or meningitis (19). This circumstance is essential in a pediatric patient subgroup in whom clinical courses may be vague, and symptoms may exist abruptly.

Complex fractures might be clinically more obvious due to a focal soft-tissue swelling or deformity of skull shape (20). However, linear fractures may not be accompanied by remarkable edema or swelling of the scalp. Since they constitute an independent risk factor for intracranial injury in pediatric patients, the diagnosis of linear fractures is crucial (21). In this aspect, the post-processing time of 3-D CT is short and does not add any additional indirect cost. Our results support that we may gain additional information without significant radiation exposure.

Contemporary developments in software technology allowed us to generate 3-D volumes from conventional 2-D data. These VR images may be sectioned in any plane and rotated in space, which provides the achievement of 3-D insight for the anatomy of the structure under investigation (22). Moreover, microanatomic structures that are not visible by conventional 2-D imaging may be shown using reconstructed images at slighter intervals. The reformatted 3-D images offer additional data regarding several circumstances, comprising genetic deformities, vascular abnormalities, inflammatory or neoplastic situations, and trauma (23).

The retrospective design, small sample size, data restricted to the experience of a single-center, and the possible impacts of socio-environmental factors are the main limitations of this study. It must be remembered that the knowledge and awareness of pediatric emergency doctors for evaluation of 2-D and 3-D CT images may significantly affect the diagnostic accuracy in head trauma patients. Further trials should be implemented to unveil the utility of 3-D reconstruction in other patient groups and clinical indications.

CONCLUSION

In conclusion, this study data yielded that 3-D reconstruction of CT scans in pediatric head trauma patients may increase the accuracy of diagnosis for skull fractures. This reformatting may yield a safe, cost-effective, and practical measure to differentiate fractures form sutures, particularly in pediatric emergency cases. Improvement of the collaboration between pediatric emergency and radiology departments, as well as the routine use of 3-D reconstruction images in the assessment of pediatric head trauma patients, are key points for the avoidance of misdiagnosis of skull fractures.

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