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Original Article

Clinical value of low-dose three-dimensional reconstruction by multi-slice spiral computed tomography and by traditional X-ray in the diagnosis of distal radius epiphyseal injury in children

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Abstract: Objective: To compare the clinical value of multi-slice spiral computed tomography (MSCT) low-dose three-dimensional reconstruction and traditional X-ray in the auxiliary diagnosis of distal radius epiphyseal injury in children. Methods: A retrospective analysis was performed on 105 children with distal radius bone scale injury (classified by Salter-Harris classification) admitted from March 2020 to June 2022. All children underwent MSCT three-dimensional reconstruction examination and traditional X-ray examination. The detection rate of epiphyseal injury of the distal radius was compared, along with the resolution, sensitivity and specificity. The image clarity and display degree of bone structure were analyzed. The radiation dose-related indicators and the time required for diagnosis were compared. Results: The detection rate and diagnostic accuracy of MSCT (100%, 92.38%) was significantly higher than that of X-ray (76.19%, 64.76%). In terms of radiation dose index, the volume dose index CTDI of MSCT ranged from 1-5 mGy while the X-ray group ranged from 5-10 mGy. The dose length product (DLP) value of the MSCT group was lower than in the X-ray group (20-100 mGy·cm vs. 50-150 mGy·cm). The diagnostic scan time for MSCT was shorter than that of conventional X-ray. The acceptance rate with MSCT was 99%, significantly higher than that with conventional X-ray (85%). Conclusions: Low-dose three-dimensional reconstruction of MSCT in the diagnosis of epiphyseal injury of distal radius in children shows significant advantages over traditional CT in the detection rate, diagnostic accuracy, postoperative reduction quality evaluation, and radiation dose.

Keywords: Low-dose MSCT, three-dimensional reconstruction, radius injury

Introduction

Epiphyseal injuries, especially those involving the distal radius, are relatively common in children and adolescents [1]. This type of injury involves the growth plate and hmay affect the normal growth of bone, making timely and accurate diagnosis crucial. Pediatric distal radius epiphyseal injury refers to a type of injury involving the growth plate of the distal radius, typically occurring during the growth period of children and adolescents. The growth plate of the distal radius is very active at this stage and therefore highly sensitive to injury [2]. Growth plate injury may affect normal bone development, so early diagnosis and treatment are very important for the bone health of children [3].

To better understand the distal radius epiphyseal injuries, the Salter-Harris (S-H) classification is often employed. This classification helps a physician understand the nature of the epiphyseal injury, facilitating the development of an appropriate treatment plan. Different types of injuries may have different effects on bone growth and joint function. The occurrence of distal radius epiphyseal injury in children is mainly related to the following aspects [4-6]. (1) Prevalence in children and adolescents: due to the activity of the growth plate, this kind of injury is relatively common in this age group. (2)

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Traumatic causes: in most cases, injuries are caused by trauma, such as sports injuries and falls. (3) Growth plate sensitivity: the growth plate of the distal radius is very sensitive to injury, potentially affecting normal bone development.

However, several challenges remain in the imaging diagnosis of epiphyseal injuries of distal radius in children. The existence of the growth plate introduces specific difficulties that necessitate more precise imaging techniques [7-9]. X-rays are the preferred initial imaging modality for detecting acute fractures, subacute healing responses, and subsequent growth disturbances [10]. However, X-rays have diagnostic limitations due to their inability to clearly visualize certain types of injuries, necessitating the use of CT or MRI for a more comprehensive assessment. While CT provides excellent skeletal detail and is beneficial in determining precise articulation and identifying small fracture fragments after acute fracture, it fails to assess cartilage growth plates and epiphyses, as well as osteochondral perfusion. Acute fractures involving the growth plate can result in high signal intensity on fluid-sensitive MRI images [11]. However, there is no consensus on the reclassification of growth plate fractures based on MRI imaging [12]; therefore, MRI imaging is currently reserved for the evaluation of suspected occult and complex fractures [13].

Low-dose three-dimensional reconstruction of multi-slice spiral CT (MSCT) is a medical imaging technique that produces high-resolution three-dimensional images of the internal body structure using multi-slice spiral CT scanning with a low radiation dose [14-16]. This technique combines advanced CT scanning techniques with the low-dose radiation principles, aiming to provide clearer and more accurate images while minimizing radiation exposure to the patient. Low-dose three-dimensional reconstruction of MSCT has a wide range of clinical applications with advantages of high resolution, lower radiation dose, and more comprehensive information. However, there are considerations such as the cost of the technology and its dependence on specific technical expertise, which need careful evaluation. As technology continues to evolve, advances in this field will provide more possibilities for more precise medical imaging.

Falkowski et al. [17] compared fracture detection, image quality, and radiation dose in patients with distal extremity fractures using 3D tomography and CT, and found that fracture assessment of peripheral extremities is reliable utilizing a low-dose 3D tomography X-ray system, with slightly reduced image quality. Nevertheless, three-dimensional reconstruction of low-dose multilayer spiral CT for the diagnosis of distal radial epiphyseal injuries in children has not yet been well documented. Therefore, this study aims to explore the clinical value of low-dose three-dimensional reconstruction of MSCT in the auxiliary diagnosis of pediatric distal radius scale injuries.

Materials and methods

Study design and patients

The clinical data of 105 children with distal radius epiphyseal injury treated in Wuxi Children's Hospital Affiliated to Jiangnan University from March 2020 to June 2022 were retrospectively analyzed. MSCT and X-ray examinations were performed before surgery. This study was approved by the ethics committee of Wuxi Children's Hospital Affiliated to Jiangnan University.

Inclusion criteria: (1) patients aged < 18 years old; (2) patients who underwent both X-ray and MSCT examination before operation; (3) patients diagnosed and classified according to Salter-Harris classification of distal radius epiphyseal injuries [18], including type I epiphyseal separation, type II epiphyseal separation with metaphyseal fracture, type III epiphyseal fracture, type IV epiphyseal and metaphyseal fracture, type V epiphyseal plate compression injury, and closed fracture without open wound; (4) patients with complete clinical and follow-up data.

Exclusion criteria: (1) patients with open fracture and local infection; (2) patients with non-traumatic fracture (pathological fracture); (3) patients with old fracture; (4) patients with surgical contraindications such as severe underlying diseases; (5) patients with previous surgical history that may affect this study; (6) patients with incomplete clinical and follow-up data.

Data collection

Baseline data of eligible patients, including gender, age, causes of fracture were collected from the patient records. Examination data, including the radiation dose related indicators, the diagnostic scan time, digital image of imaging examinations, were also collected.

Examination methods

For diagnosing distal radius epiphyseal injury in children, appropriate positions for X-ray and MSCT imaging were selected based on the provided information.

(1) Posterior-anterior position of wrist joint: the subject was seated with the wrist joint in a posterior-anterior position and the elbow bent at about 90°. The hand was half clenched, with the palm of the wrist close to the table, and the wrist joint placed in the center of the detector. The radiation field and detector included the distal ulna, radius and proximal metacarpal bones. The source-image distance was 100.0 cm. The center line was aligned to the midpoint of the line connecting the styloid processes of the ulna and radius and shot vertically into the center of the detector. The wrist bones were located in the middle of the image and displayed in the anteroposterior position.

(2) Lateral view of wrist joint: the subject was seated at the side of the photographic table with the elbow bent at about 90°. With the fingers and forearm on their side, the fifth metacarpal bone and the ulnar side of the forearm were close to the photographic table, and the ulnar styloid process was placed in the center of the detector. The source-image distance was 100.0 cm. The center line was aligned to the styloid process of the radius and projected vertically into the center of the detector.

(3) Wrist joint abduction position: the subject was seated facing the photography table, bending the elbow naturally, with the palm down. The wrist was placed flat on the board at 20° angle from the examination table (or 20° higher with a sandbag), and the palm shifted to the ulnar side as far as possible. The source-image distance was 100.0 cm. The center line was perpendicular to the midpoint of the line connecting the ulnar and radial styloid processes and was injected into the center of the detector.

The choice of position was determined according to the specific condition, symptoms and the clinical judgment of the doctor. These three positions are usually used to comprehensively evaluate the anatomy of the wrist joint to support the diagnosis of distal radius epiphyseal injury in children.

Image interpretation and analysis

All scans were analyzed independently by two radiologists and two orthopedic surgeons to ensure unbiased assessment. All radiologists individually used the workstation. Prior to the evaluation, observers were given sample images and grading scales.

Three observers were then asked to rate the scans of cortical bone, bony trabeculae, articular surfaces, and soft tissue using a 5-category visual grading scale. They also assessed the extent and major types of artifacts, considering their effect on image assessment (i.e., whether the observers found the diagnosis of a fracture difficult due to artifacts). The observer also determined the Salter-Harris classification and measured the cortical disruption and the length of the fracture gap. Salter-Harris classification served as a reference for the evaluation. The final classification was determined by consensus between an expert (a board-certified radiologist with 20 years of experience) and two radiologists (with 5-10 years of experience, not one of the observers) as a reference standard.

Outcome measure

The primary outcome was the diagnostic detection rate. The number of cases detected by the two methods (MSCT and X-ray) was recorded. Secondary outcome: (1) The number of cases of different types diagnosed by the two methods; (2) Radiation dose related indicators; (3) Diagnostic scan time; (4) Diagnostic satisfaction of the patients.

Statistical methods

SPSS 25.0 software was used for statistical analysis. Measured data were expressed as mean ± standard deviation (x±s). Normality and homogeneity of variance were tested. Independent sample t test was used for the comparison between groups. Counted data were expressed as percentage (%) and analyzed by *chi-square* test. GraphPad was used for data visualization. $P < 0.05$ was considered a significant difference.

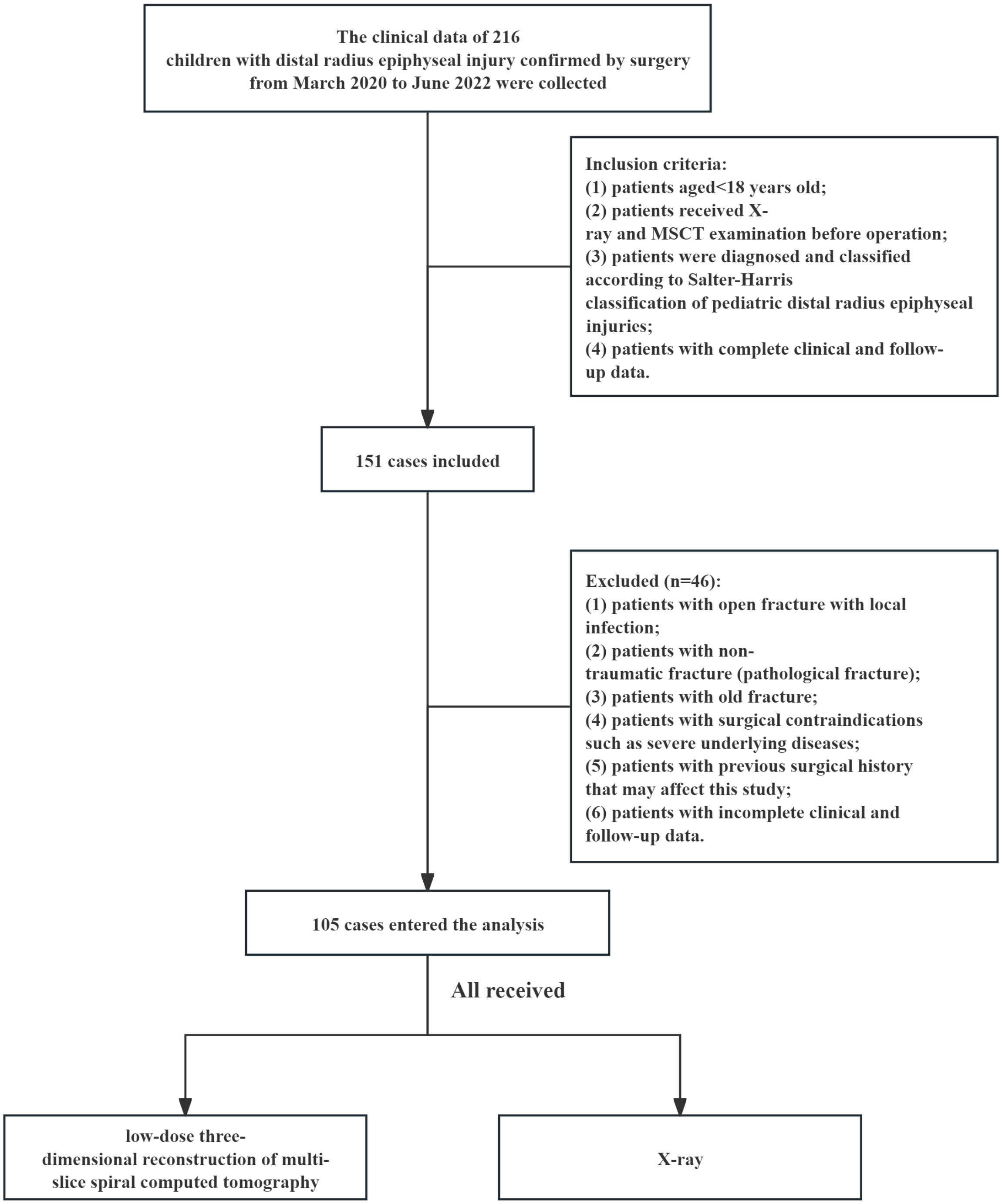

Figure 1. Flow chart detailing the selection of patients included in this study.

Results

General information of the patients

After screening, 105 patients, including 58 males and 47 females, were included (**Figure 1**). The mean age of the patients was (10.87±5.49) years ranged from 5-15. The causes of fracture included traffic accident in 18 cases, falling from height in 30 cases, and falling or heavy object injury in 57 cases, as show in **Table 1**.

Diagnostic detection rate

Low-dose three-dimensional reconstruction of MSCT diagnosed 105 children with distal radius epiphyseal injury, while X-ray detected 80

Table 1. General information of the children

Characteristic	Cases (n=105)
Gender	
Male	58 (55.2)
Female	47 (44.8)
Age	10.87±5.49
Causes of fracture	
Traffic accident	18 (17.1)
Falling form height	30 (28.6)
Falling or heavy object injury	57 (54.3)

cases. The detection rate of MSCT was 100%, which was significantly higher than 76.19% of X-ray (P < 0.05, **Table 2**).

Diagnostic classification

MSCT diagnosed 16 cases of type I epiphyseal separation, 49 cases of type II epiphyseal separation with metaphyseal fracture, 3 cases of type III epiphyseal fracture, 28 cases of type IV epiphyseal and metaphyseal fracture, and 1 case of type V epiphyseal plate compression injury. X-ray examination diagnosed 10 cases of type I epiphyseal separation, 35 cases of type II epiphyseal separation with metaphyseal fracture, 1 case of type III epiphyseal fracture, and 22 cases of type IV epiphyseal and metaphyseal fracture. The diagnostic accuracy of MSCT (92.38%) was significantly higher than that of X-ray (64.76%) (P < 0.05), as shown in **Table 3**.

Radiation dose-related indicators

In terms of radiation dose index, the volume dose index CTDI of MSCT group ranged from 1-5 mGy, while that of the X-ray ranged from 5-10 mGy (P < 0.05). The dose length product (DLP) value of MSCT ranged from 20-100 mGy·cm, while that of the conventional X-ray ranged from 50-150 mGy·cm. The effective dose (ED) of MSCT ranged from 1-5 mSv, and that of conventional X-ray ranged from 2-8 mSv. The size-specific dose estimate (SSDE) was relatively low in the MSCT but varied according to the size of the patient, as shown in **Figure 2**.

The diagnostic scan time and patient satisfaction

The average scan time of MSCT was 10-20 seconds, which was significantly shorter than

Table 2. Distal radial epiphyseal injury in children

	n	Number of cases	Detection rate
MSCT	105	105	100%
X ray	105	80	76.19%
chi-square		28.381	
P		< 0.0001	

20-30 seconds for the conventional X-ray (P < 0.05). The acceptance rate of the MSCT was 99%, which was notably higher than 85% of the conventional X-ray (P < 0.05), as shown in **Figure 3**. The images of a typical case are shown in **Figure 4**.

Discussion

Medical decisions are made by considering the well being of a patient and evaluating potential benefits and risks like radiation hazard. Many studies have evaluated low-dose CT to decrease patient radiation exposure without loss of diagnostic performance [19]. Since ionizing radiation exposure in pediatric medical settings is primarily due to CT examinations, each CT examination should be performed only when it provides potential clinical benefits to the child. The radiation dose (RD) of conventional CT is significantly higher than that of X-ray plain films, and increased RD is associated with an increased risk of radiation-induced cancer [20]. The dose of CT radiation depends primarily on patient-related factors and CT acquisition parameters [21].

In this study, low-dose 3D reconstruction of MSCT outperformed traditional X-ray examination in the detection rate and diagnostic accuracy of epiphyseal injuries of the distal radius in children. The results showed that the detection rate of MSCT was 100%, while that of X-ray was only 76.19%, and the difference was statistically significant. Thus, MSCT was more sensitive for the diagnosis. The diagnostic accuracy of MSCT was 92.38%, which was significantly higher than that of X-ray (64.76%). MSCT can produce three-dimensional images using 3D reconstruction technology, leading to a clear observation of the 3D space of the bone fracture. Raniga et al. [22] reported that MSCT had a higher detection rate for bone fractures than thin-slice CT and could directly observe the fracture degree and shape. However, X-rays

Table 3. Accuracy rate for classification diagnosis

Group	n	Type 1 (n=17)	Type 2 (n=51)	Type 3 (n=4)	Type 4 (n=31)	Type 5 (n=2)	Accuracy rate
MSCT	105	16	49	3	28	1	97 (92.38%)
X ray	105	10	35	1	22	0	68 (64.76%)
chi-square							20.271
P							< 0.0001

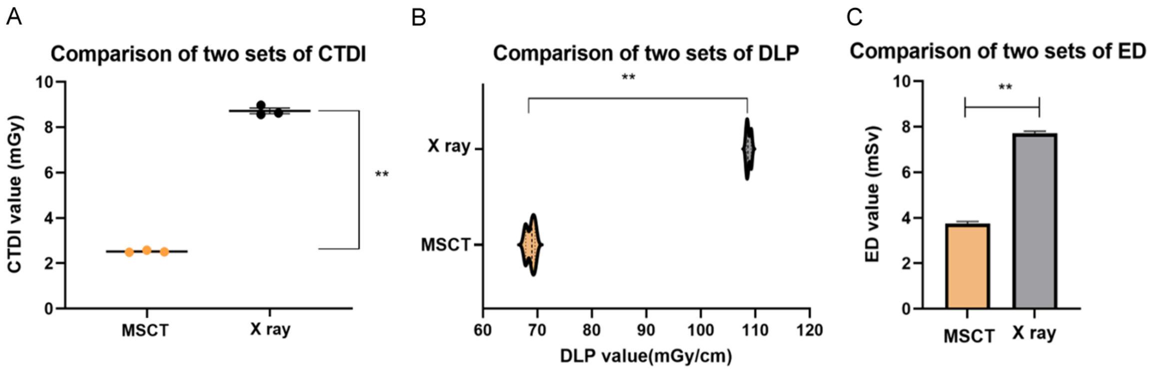

Figure 2. Comparison of radiation dose-related parameters between the two diagnostic methods. A: CTDI value of the two imaging modalities; B: DLP value of the imaging modalities; C: ED value of the imaging modalities. **P < 0.01.

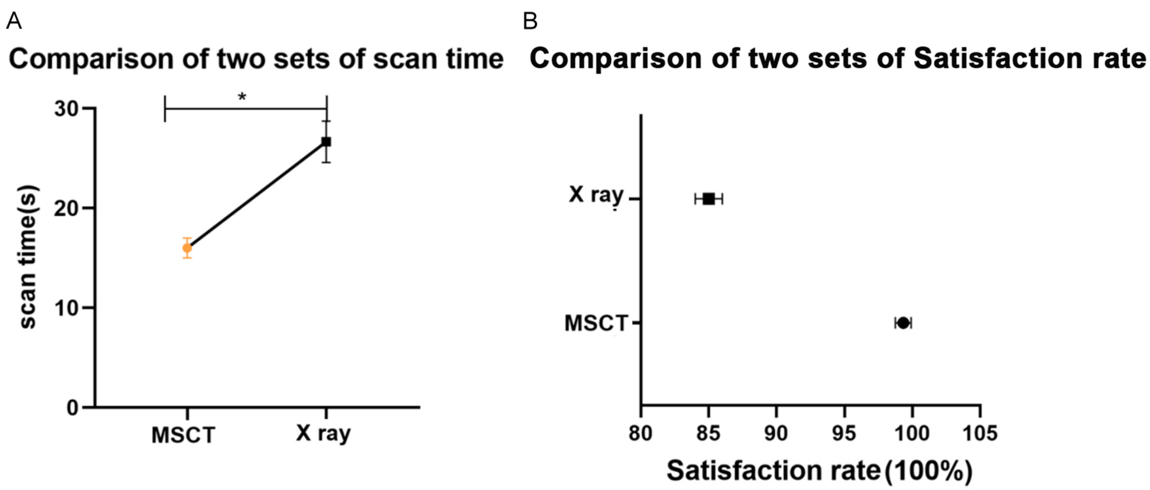

Figure 3. Comparison of scanning time and patient satisfaction with the imaging modalities. A: Scan time; B: Satisfaction rate. *P < 0.05.

form chiaroscuro images due to the differential absorption of X-rays by various tissue structures. Studies have shown that X-ray examinations are prone to misdiagnosis owing to the complex structure of the skeleton and various influencing factors [23]. Our results also demonstrated that MSCT had higher diagnostic accuracy.

In terms of radiation dose, the volume dose index (CTDI), dose length product (DLP), effective dose (ED) and size-related dose estimate (SSDE) of MSCT were lower than those of conventional X-ray. This indicated that low-dose 3D reconstruction of MSCT has obvious advantages in radiation dose, and can reduce the radiation exposure of patients. Although bones are

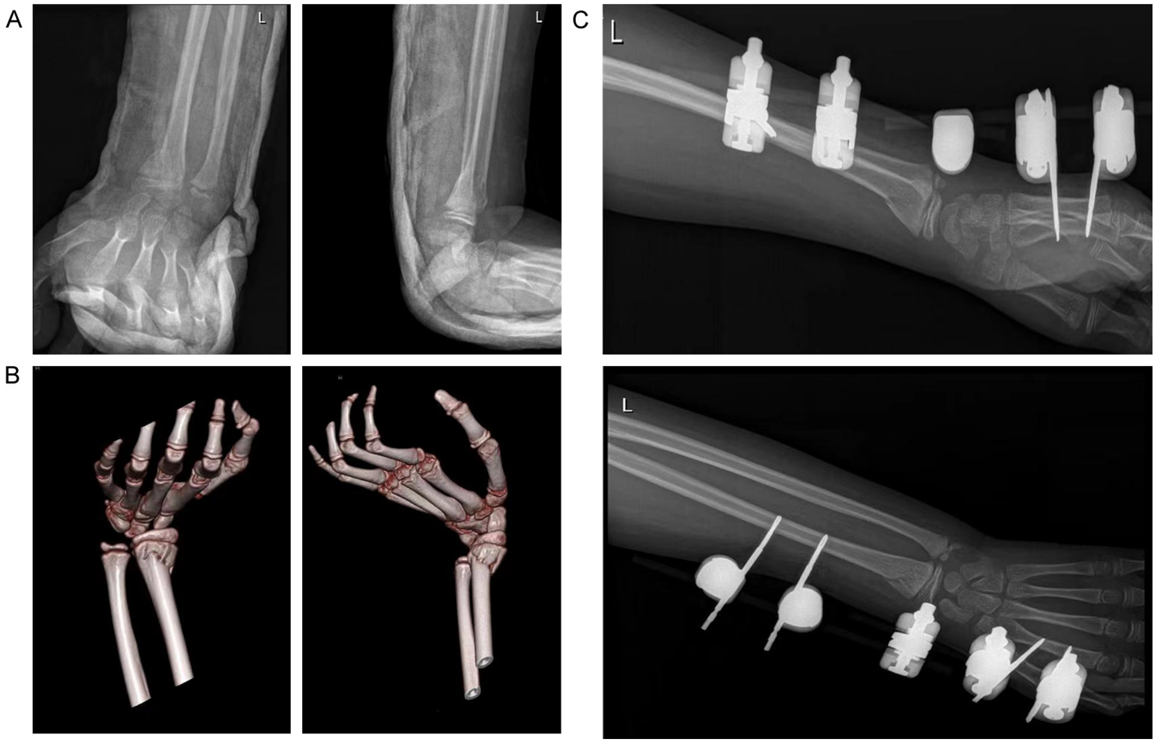

Figure 4. The images of the typical clinical case. A: X-ray imaging shows epiphyseal injury of the distal radius before treatment; B: 3D imaging of distal radius of the case; C: X-ray after orthopedic reduction of distal epiphyseal fracture of the radius.

the least affected by radiation, the bone marrow within bones is the most radiation-sensitive organ in the body. The increased use of MSCT has led to more CT scans being ordered by clinicians without always considering the associated radiation exposure. Therefore, studies are now focusing on reducing radiation exposure from skeletal CT [24-27]. For extremity imaging, Moritz et al. [28] demonstrated that ultra-low-dose CT (up to 11 mA) showed sufficient diagnostic performance for fractures, despite the significant radiation reduction. Also, in a study of cervical spine trauma, Mulkens et al. [29] reported that low-dose CT increased image noise; however, the increased noise did not affect subjective image quality.

In addition, the diagnostic scan time of MSCT (10-20 seconds) was significantly shorter than that of the conventional X-ray (20-30 seconds), indicating that MSCT is able to complete the diagnostic scan in a shorter time with the same diagnostic efficiency. At the same time, patient acceptance was higher with MSCT (99%) compared to 85% with X-ray. This may be related to the shorter scan time of MSCT and lower radiation exposure to patients, which further improves patient comfort. Performing radiographs or CT scans on children presents several technical challenges, including the child's size, the dispersed X-ray beam, and the child's level of cooperation [30]. The Royal College of Radiologists (RCR) notes that skeletal investigations can be distressing for children, their families and staff, particularly due to the requirement for immobilization [31]. Younger children often require immobilization to minimize motion artifacts, and repeat imaging may be necessary, increasing the cumulative radiation dose [32]. The linear no-threshold theory states that an increase in radiation dose is directly proportional to an increase in the risk of radiation-related cancers [33]. Current evidence suggests that exposure to 10 mSv of radiation increases the risk of malignant tumors by 1:2000, and children are more susceptible to radiation-related malignant tumors [34]. Thus, the findings of our study are particularly important for pediatric patients, especially when repeated examinations are required.

Limitationsof this study include possible selection bias and sample size limitations. Future studies could further expand the sample size and consider more clinical factors to verify the generalizations of these results. In addition, comparing patients across different age groups and varying injury types could provide a more comprehensive evaluation of the performance of low-dose 3D reconstruction of MSCT in diverse clinical scenarios [35-37].

In conclusion, low-dose 3D reconstruction of MSCT demonstrates significant clinical value in the diagnosis of epiphyseal injuries of the distal radius in children, providing patients with more accurate and low radiation imaging evaluation. The application of this technique is expected to evolve into a routine method in pediatric orthopedic imaging.

Disclosure of conflict of interest

None.

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