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Image Fusion of X-ray and Magnetic Resonance Imaging-Based Evaluation of the Stability of Pediatric Lateral Humeral Condyle Fracture

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Abstract

Background: Lateral humeral condyle fracture is the second most common intra-articular fracture in pediatric elbow.
Objectives: The present study aimed to analyze the differences between X-ray and magnetic resonance imaging (MRI) in the evaluation of the stability of pediatric lateral humeral condyle fracture and the degree of fracture displacement.
Methods: A total of 78 patients with acute elbow trauma were selected and hospitalized in our orthopedic department from July 2018-July 2019. All patients were examined with X-ray and MRI. The sensitivity and specificity of X-ray and MRI in the diagnosis of lateral humeral condyle fracture and the integrity of the trochlear cartilage chain fracture were calculated. The X-ray and MRI were examined respectively to check the value of lateral and posterior fracture space of lateral humeral condyle fracture.
Results: Callus repair was observed according to the observation of fracture line during operation or the follow-up imaging examination of conservative treatment. It was confirmed that out of 78 patients with elbow joint trauma, 72 cases were diagnosed with the fracture of lateral condyle of humerus, and the other 6 patients were cured without fracture signs. The sensitivity of MRI in the diagnosis of pediatric lateral condylar fracture was 100%, which was significantly higher than that of X-ray (88.89%) ($P<0.05$). The results of X-ray and MRI in the diagnosis of pediatric lateral condylar fracture were generally consistent (kappa value = 0.465;< 0.01). Among the 72 confirmed cases, 35 subjects had a fracture of trochlear cartilage chain. The sensitivity of MRI in the diagnosis of pediatric fracture of lateral condyle of humerus was 97.14%, which was significantly higher than that of X-ray (62.86%) ($P<0.05$). The difference was statistically significant ($P<0.05$). The sensitivity of 3d-fs-fspgr or 3d-fspgr was significantly higher than that of fs-t2wi and fs-pdwi ($P< 0.05$).
Conclusion: As evidenced by the obtained results, MRI was superior to X-ray in the diagnosis of pediatric humeral epicondylar fracture stability and evaluation of fracture displacement. Furthermore, 3d-fs-fspgr or 3d-fspgr was the best MR sequence to show the pediatric humeral epicondylar fracture. These findings can provide theoretical basis for the establishment of clinical treatment plan.

Keywords: Degree of displacement, Fracture of lateral condyle of humerus, MRI, Stability, X-Ray

1. Background

Lateral humeral condyle fracture is the most common intra-articular fracture in pediatric elbow. It refers to the joint fracture of the humeral lateral condyle with the capitulum of the humerus or the external lateral condyle of the humerus and the partial epiphysis of the trochlear bone, accounting for 12%-20% of pediatric elbow fractures. The incidence of pediatric fractures is second only to supracondylar fractures of the humerus, commonly occurring in children between 5-12 years old (1). Children with lateral humeral fractures often show lateral swelling which gradually spread to the entire joint with ecchymosis and elbow cubitus malformation which involves various mechanisms.

There are currently two main kinds of theories: thrust injury theory and tensile injury theory. According to the thrust injury theory, the fracture of the humerus condyle is caused by the impact of the radial head and the humeral head, forming a fracture line. On the other hand, based on the tensile injury theory, at the moment of violence, the forearm extensor muscle group has a strong contraction, causing the attachment point of the lateral condyle extensor muscle group to detach, leading to fracture (2). Since the fracture line often involves the distal humerus articular surface to form intra-articular fractures, serious complications and joint dysfunction cannot be avoided in later stages.

Clinical requirements need the timely and accurate judgment of fracture stability and anatomical reduction, which has normal meaning in the improvement of normal development of pediatric elbow joints. The majority of lateral condyle fractures require surgical treatment; nonetheless, various treatment or surgical methods can be selected depending on the specific site and type. The currently used treatment methods include external fixation with plaster or splint after manual reduction, internal fixation with percutaneous puncture needle after manual reduction, and internal fixation with open reduction.

At the present, the diagnosis of lateral humeral condyle fractures mainly relies on imaging examinations, among which, elbow X-ray is still the preferred method. Nonetheless, since distal humerus epiphyseal ossification is not complete in children, it

is difficult to make accurate judgments about the damage of the articular epiphyseal cartilage. Therefore, it is difficult to determine the presence of cartilage for the lateral humeral fractures with little or no displacement (3). The X-ray examination is extensively used in the diagnosis of pediatric lateral humeral condyle owing to its convenience, low cost, and high popularity; moreover, it has a wide range of characteristics.

Fracture classification based on X-ray examination results is relatively simple and practical. After making a clinical judgment based on X-ray results, some children still have a poor prognosis of lateral humeral condyle fractures in actual clinical work. In the early X-ray diagnosis, the lateral condylar humerus fractures without obvious displacement are prone to secondary fracture displacement during conservative treatment (4,5). The younger patients have more cartilages. The X-ray film only demonstrates the epicondylar center of the humeral epicondyle and the metaphyseal fracture, and no cartilage can be observed.

The X-ray signs of injury are often difficult to discern and physicians need to understand the anatomy and pediatric elbow bone age and give a full estimate of the size of the fracture in the clinic. Fracture dislocation is not timely detected or the degree of fracture displacement is underestimated in many of these children, leading to delayed surgery and serious complications, such as delayed fracture healing and nonunion (6).

In comparison with X-ray examination, Magnetic Resonance Imaging (MRI) is recognized as the best method for examining joint soft tissue damage. This multi-directional multi-parametric imaging modality can clearly display the structure of the elbow joint during the examination process better than other imaging examination methods (7). The high resolution of soft tissue and non-ionize radiation can reflect the pathological changes of cartilage, ligaments, marrow, and other joint accessory structures that cannot be detected by plain X-ray and Computed tomography (CT) examination (8).

The imaging principle of MRI is different from CT and X-ray plain films, and it provides a better resolution of soft tissues, as compared to the other two methods. It is of great significance in understanding the degree of fracture injury to judge fracture stability and guide internal fixation surgery. The MRI examination is non-invasive, non-radiative, and the patient is easy to accept (9). Some researchers have confirmed (10) that one of the joint discs is closely related to the degree of displacement of the condyle fracture, and MRI diagnosis is required to facilitate the preparation of surgical treatment plans.

2. Objectives

In light of the aforementioned issues, the present study aims to analyze the X-ray and MRI evaluation of the stability of pediatric lateral humeral condyle fracture and the difference in the degree of fracture displacement.

3. Methods

3.1. General Information

From July 2018 to July 2019, 78 patients with acute elbow trauma hospitalized in our orthopedic department were selected as the research participants. All patients had suspected lateral humeral fractures. This study was approved by the hospital ethics committee. The inclusion criteria were as follows: (1) age range of 0-14 years, (2) diagnosed or suspected lateral humeral fracture upon admission, (3) patients with complete clinical medical records and imaging examination records (7), patients who can be followed up for more than three months (10). Families of patients were informed and agreed to participate in the study.

On the other hand, the exclusion criteria entailed: (1) being diagnosed with humeral condyle fracture and other types of the elbow injury, (2) injuries which lasted for more than two weeks, (3) multiple body fractures, such as pathological fractures, re-fractures, and bone metabolic diseases, (7) patients with incomplete or missing medical records, imaging, or unable to be follow-up, (10) patients who could not judge the degree of fracture displacement due to artifacts in the MRI examination images due to insufficient cooperation during examination, (11) infection and tumor lesions. In terms of gender, the majority of subjects (n=49) were male, and regarding age, they were within the age range of 0-14 years (mean age of 5.89±2.35 years). There were 45 cases of left elbow fractures and 33 cases of right elbow fractures. Moreover, the mean follow-up time for this group of patients was obtained at 10.65±7.48 weeks.

3.2. Experimental Instruments

Both the elbow joint orthophoria and lateral images were obtained by Discovery XR656 digital X-ray machine (purchased from General Electric Company). The projection conditions of the elbow joint orthophoria and lateral positions were as follows: tube voltage: 60 kV, tube current: 5 mAs, photography distance: 100 cm, field of view: 24 × 30 cm. The anterior-posterior centerline of the elbow joint is 2 cm from the midpoint of the inner and outer epicondyle of the humerus, and the lateral centerline of the elbow joint is 4 cm from the medial surface of the posterior surface of the olecranon.

The MRI examination uses 3.0T nuclear MRI (purchased from General Electric Company). The elbow scan uses eight-channel phased array shoulder coil, elbow MRI includes five examination sequences, including coronal FS-T2WI, coronal FS-PDWI 3, coronal 3D-FS-FSPGR or 3D-FSPGR. The scan line of

these three coronal sequences should be parallel to the long axis of the middle and lower humeral shaft parallel to the internal and external condyle line of the humerus.

The axial FS-T2WI scan line is parallel to the distal humeral articular surface which encompasses the epiphysis of the distal humerus to the radius nodules. The scan line of the sagittal plane FS-T2WI is perpendicular to the internal and external condyle lines of the humerus; moreover, it is parallel to the long axis of the middle and lower humerus. The observation of the X-ray image of the elbow joint and the degree of fracture displacement was performed by Fuji's AYNAPSEPASC system. The degree of fracture displacement on the MRI image was measured by the US GE Workstation.

3.3. Inspection Method

All patients were admitted to the hospital with elbow joint trauma, and the lateral condyle fracture of the humerus was highly suspected after routine X-ray examination of the elbow joint. The MRI examination of the elbow joint was performed after the fixation of the long-arm cast. Moreover, 0.5mg/kg 10% chloral hydrate (for enema) was administered if the younger children were unable to cooperate, and an MRI examination was conducted after they slept. An observation of the fracture line during surgery or follow-up imaging of conservative treatment revealed that callus repair is the standard for making a judgment about the presence of lateral humeral condyle fracture.

The sensitivity and specificity of X-ray and MRI in the diagnosis of lateral condylar fracture of humerus and the integrity of trochlear cartilage chain fracture were calculated. The X-ray and MRI were assessed respectively to check the value of lateral and posterior fracture space of lateral condylar fracture of humerus. In addition, the difference in the degree of fracture displacement between the two examination methods was evaluated.

3.4. Definition of Observation Indexes and Image Judgment

The definition of fracture by X-ray is to observe the low-density transparent line shadow of the epiphyseal end of the humerus or the displacement and separation of the humeral capitellum epiphysis (Figure 1). The definition of fracture by MRI is to find the low-signal fracture line in the high-density transparent line shadow or the humeral lateral condyle metaphysis or distal humeral cartilage in the coronal, sagittal, or axial shadow sequence (Figure 2). For imaging judgment of the integrity of the humerus cartilage chain, in X-rays, the integrity of the humerus cartilage chain can be inferred from the displacement of the fracture block, the separation distance, or the separation of the humeral capitellum and epiphysis. In the X-ray film, the integrity of the humeral trochlear cartilage chain can be considered when the fracture displacement is less than 2 mm. In addition, a displacement greater than 2 mm is indicative of the fracture of the humeral trochlear cartilage chain (Figure 3). In MRI, whether the fracture involves and penetrates the cartilage of the distal humerus through different sequences to determine the integrity of the trochlear cartilage chain can be observed (Figure 4).

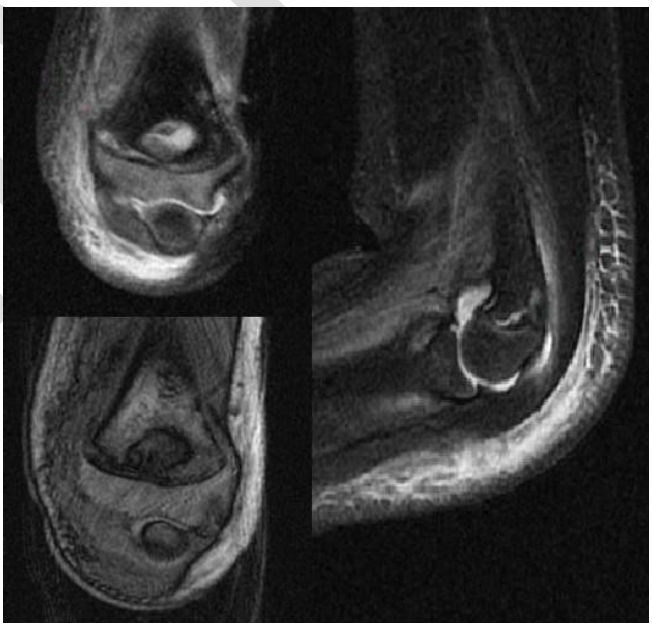

Figure 1. X-ray of the lateral view demonstrating the fracture of the epiphysis of the right lateral humerus and the distal triangular fracture

Figure 2. Upper left coronal position FS-T2WI displaying shows the high signal fracture line of the lateral epicondyle metaphysis of the humerus. The lower left figure displays the coronal position 3D-FSPGR, illustrating the oblique high-signal fracture line of the metaphysis of lateral condyle of the humerus.

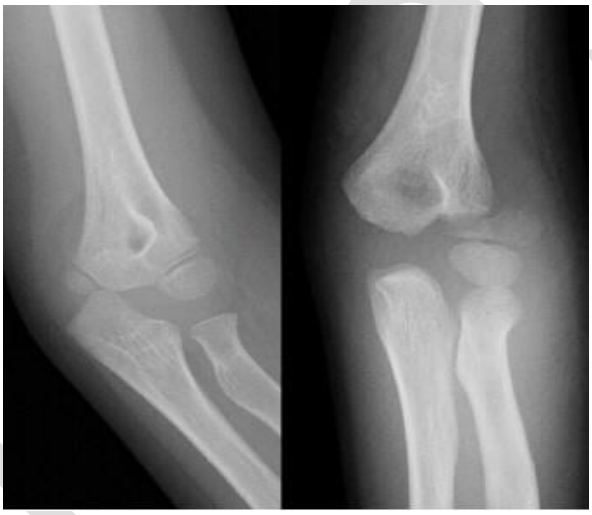

Figure 3. X-ray shows no obvious separation and displacement of the fracture block on the left, and the cartilage chain structure is intact. The right condyle fracture block is clearly divided, the cartilage chain on the right is completely broken, and the epiphysis of the humerus is displaced.

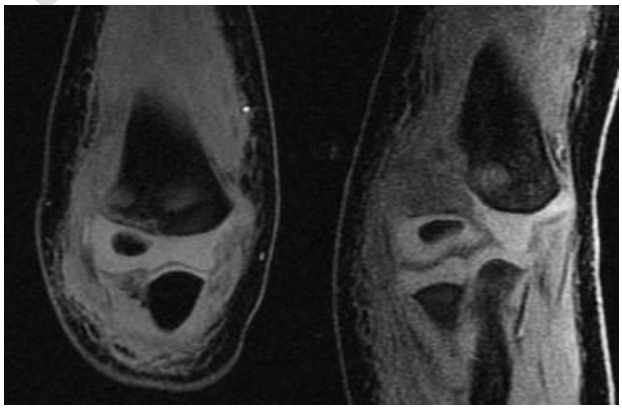

Figure 4. As depicting in the left picture, Coronal 3D-FSPGR sequence illustrates the complete cartilage chain, and the fracture line is limited to the epiphysis of the lateral condyle of the humerus.

3.5. Statistical Methods

The obtained data were statistically analyzed in SPSS software (version 20.0) using the Kappa consistency test for the diagnosis of the consistency of fracture and humerus cartilage chain integrity by X-ray and MRI examination. Moreover, the paired χ^2 was employed to compare two diagnostic test results. The criterion is as follows: Kappa≥0.75 signifies that the diagnostic results of the two methods are in good agreement, 0.4≤Kappa <0.75 indicates that the diagnostic results of the two methods are generally consistent, and Kappa <0.4 suggests that the diagnostic results of the two methods are barely the same. The X-ray and MRI measurements of the lateral and posterior fracture space of pediatric lateral humeral condyle fractures were expressed as mean ($\bar{X} \pm S$), and the data of the two groups were compared by t-test. The qualitative variables were expressed by [n (%)], and the χ^2 test was employed. For the comparison of data between groups, P<0.05 was considered statistically significant.

4. Results

4.1. Comparison of the Effectiveness of X-ray and Magnetic Resonance Imaging in the Diagnosis of Lateral Humeral Fracture of Children

Observation of the fracture line during surgery or follow-up imaging examination of conservative treatment revealed repair of the callus. It confirmed that out of 78 patients with elbow trauma, 72 cases were diagnosed with lateral humeral condyle fracture, and the other 6 patients were cured without fracture signs. The sensitivity of MRI diagnosis of pediatric humeral lateral condyle fracture is 100%, which is significantly higher than that of X-ray examination (88.89%). The difference is statistically significant (P<0.05). The results of X-ray and MRI in the diagnosis of pediatric lateral condylar fracture were generally consistent (Kappa value= 0.465; P<0.01) (Table 1).

4.2. Comparison of X-ray and Magnetic Resonance Imaging Diagnosis of Humerus Cartilage Chain Integrity in Children with Humeral Lateral Condyle Fracture

Among the 72 confirmed cases, 35 cases had the fracture of the trochlear cartilage chain. The sensitivity of MRI in the diagnosis of pediatric fracture of lateral condyle of humerus was 97.14%, which was significantly higher than that of X-ray examination (62.86%), which is statistically significant (P< 0.05). The consistency of X-ray and MRI in the diagnosis of pediatric fracture of lateral condyle of humerus was poor (Kappa = 0.122; P>0.05) (Table 2).

4.3.Comparison of the Effect of X-ray and Magnetic Resonance Imaging in Diagnosing the Degree of Displacement of Pediatric Humeral Lateral Condyle Fractures

Two examination methods were used to determine the degree of displacement of pediatric lateral humeral condyle fracture. The X-ray measurements of the lateral and posterior fracture space of the pediatric lateral humeral condyle were significantly smaller than the MRI measurement values, and the difference was statistically significant (P<0.05) (Table 3).

4.5.Magnetic Resonance Imaging Coronal Sequence of Different Sequences for the Diagnosis of Humeral Lateral Condyle Fractures of Cartilage Fractures in Children

There are differences in the sensitivity of three sequences of MRI coronal position diagnosis of lateral humeral condyle fractures of cartilage fractures in children (P<0.05). Based on pairwise comparison analysis, the diagnostic sensitivity of coronary 3D-FS-FSPGR or 3D-FSPGR is significantly higher than that of coronary FS- T2WI and coronary FS-PDWI sequences, and the difference was statistically significant (P<0.05) (Table 4).

4.6.Comparison of Magnetic Resonance Imaging FS-T2WI Sequence of Different Directions for the Diagnosis of Lateral Humeral Condyle Fracture of Cartilage Fracture in Children

The comparison of FS-T2WI sequence of MRI examination of coronal, sagittal, and axial directions for the diagnosis of pediatric lateral humeral condyle fracture cartilage fracture revealed no statistical difference (P>0.05) (Table 5).

Table 1. Comparison of the effect of X-ray and magnetic resonance imaging diagnosis of pediatric lateral humeral fracture

Method	Case	True positive	Ture negative	False positive	False negative	Sensitivity	Specificity	Kappa	*P*
X-ray	78	64	6	0	8	88.89%	100%	0.465	0.029
Magnetic resonance imaging	78	72	6	0	0	100%	100%	*P*<0.001	

Table 2. Comparison of the integrity of trochlear cartilage chain of humerus diagnosed by X-ray and magnetic resonance imaging diagnosis of pediatric humeral lateral condyle fracture

Method	Case	True positive	Ture negative	False positive	False negative	Sensitivity	Specificity	Kappa	*P*
X-ray	78	22	39	4	13	62.86%	90.70%	0.122	0.003
Magnetic resonance imaging	78	34	43	0	1	97.14%	100%	*P*=0.173	

Table 3. Comparison of the effect of X-ray and magnetic resonance imaging in diagnosing the degree of displacement of pediatric lateral humeral condyle

Method	Case	Lateral fracture space (mm)	Posterior fracture space (mm)
X-ray	78	2.08±0.97	2.15±0.88
Magnetic resonance imaging	78	2.44±1.26	2.46±1.01
t		2.000	2.044
P		0.047	0.043

Table 4. Comparison of the effects of different sequences of magnetic resonance imaging coronal position on diagnosis of pediatric humeral lateral condyle fractures of cartilage fractures

Method	Case	True positive	Ture negative	False positive	False negative	Sensitivity	Specificity	Kappa
Coronal FS-T2WI	78	65	5	1	7	90.28%	83.33%	χ^2=7.009
Coronal FS-PDWI	78	62	7	0	9	87.32%	100%	*P*=0.025
Coronal 3D-FS-FSPGR or 3D-FSPGR	78	71	7	0	0	100%	100%	

Table 5. Comparison of the effects of MRI FS-T2WI sequence of different directions in diagnosis of pediatric humeral lateral condyle fractures of cartilage fractures

Method	Case	True positive	Ture negative	False positive	False negative	Sensitivity	Specificity	Kappa
Coronal FS-T2WI	78	65	5	1	7	90.28%	83.33%	χ^2=3.343
Sagittal FS-T2WI	78	59	5	1	13	81.94%	83.33%	*P*=0.167
Axial FS-T2WI	78	56	7	0	15	78.87%	100%	

5. Discussion

Lateral humeral condyle fractures are mostly fractures are the second most common intra-articular fracture after supracondylar fractures of the humerus. It easily occurs in children around 6 years old (1). The accurate judgment of the degree of fracture displacement is of great significance for clinical classification and treatment selection. In the absence of golden treatment time and appropriate treatment, it often leads to serious sequelae, such as cubitus varus, cubitus valgus, and fishtail malformation, which will affect the child's life in the future. Therefore, rich clinical experiences and imaging judgment are necessary for the treatment of lateral humeral fractures (11). In recent years, the development of new materials has promoted the development of internal fixation of humeral lateral condyle fractures; nonetheless, the therapeutic effect still requires long-term follow-up observation.

The X-ray examination of all elbow joint injuries is the basis of diagnosis. The accuracy of X-ray evaluation of pediatric lateral humerus condyle has become a demanding issue in clinical diagnosis and treatment. In addition, many scholars have pointed out that after external fixation of humeral lateral condyle fracture without obvious displacement on X-ray plain film, some patients have secondary fracture displacement and may develop serious complications (12). In recent years, scholars at home and abroad have devoted assiduous attention to the stability of lateral condyle fractures without obvious displacement; moreover, they have constantly questioned the accuracy of X-ray diagnosis.

If there is obvious separation and displacement of the fractured end or rotation of the fracture block, X-ray examination can conclude that the fracture is unstable. Nevertheless, the distance between the humeral center of the capitellum and the metaphysis on the X-ray film varies greatly with age and exposure position. If there is obvious separation and displacement of the fractured end or rotation of the fracture block, X-ray examination can conclude that the fracture is unstable (13). However, it is difficult to accurately determine the fracture stability of the lateral humeral condyle fracture without obvious displacement (<2 mm) on the X-ray film.

The MRI as the preferred modality for examining bone and soft tissues has become the current best imaging examination method. It is imaged from the sagittal and axial positions, which can distinguish local fluid exudation or hematoma caused by small bone changes. Callus repair was observed according to the observation of fracture line during operation or the follow-up imaging examination of conservative treatment. It was confirmed that out of 78 patients with elbow joint trauma, 72 cases were diagnosed with the fracture of lateral condyle of humerus, and the other 6 patients were cured without fracture signs.

The sensitivity of MRI in the diagnosis of pediatric lateral condylar fracture was 100%, which was significantly higher than that of X-ray (88.89%). The results of X-ray and MRI in the diagnosis of pediatric lateral condylar fracture were generally consistent (kappa value=0.465; P<0.01). Therefore, the results of the current study suggested that children with humeral lateral condyle fractures should undergo MRI examination to confirm the diagnosis.

The integrity of the lateral condylar fracture of humerus and the trochlear cartilage chain of humerus is an important anatomical factor in deciding on the

use of surgical treatment or conservative treatment. Some foreign scholars have confirmed through pediatric biomechanical experiments (14) that the integrity of the humerus cartilage trochlear chain determines the stability of pediatric lateral humeral condyle fracture. Complete or incomplete disconnection of the cartilage trochlear chain resembles a "metal hinge". The fixation of the epicondylar fracture in situ will not lead to instability and secondary displacement of the fracture.

Numerous X-ray diagnostic criteria are currently available for judging the integrity of humerus cartilage trochlear chains in lateral humeral fractures (15). The results of the present study demonstrated that out of 72 patients, 35 cases were diagnosed with cartilage trochlear chain. The sensitivity of MRI in the diagnosis of pediatric fracture of lateral condyle of humerus was 97.14%, which was significantly higher than that of the X-ray examination (62.86%) ($P< 0.05$). The consistency of X-ray and MRI in the diagnosis of pediatric fracture of lateral condyle of humerus was poor (Kapa=0.122; $P>0.05$). Therefore, the results of the present study indicated that X-ray examination is not sufficient for judging the stability of the humerus lateral condyle fracture and speculating about the integrity of the humerus cartilage trochlear chain.

Furthermore, MRI is required to clarify the humerus cartilage trochlear chain continuity so as to guide the decision of treatment. To a large extent, the degree of displacement of pediatric humeral lateral condyle fracture determines the treatment method. Children with lateral humeral condylar fractures with a degree of fracture displacement > 2 mm generally adopt open or closed reduction internal fixation. Children with lateral humeral condylar fractures with a degree of fracture displacement <2 mm are often treated with long-arm cast external fixation which requires reliance on accurate assessment of the degree of fracture displacement.

6. Conclusion

As evidenced by the results of the present study, X-ray measurements of lateral and posterior fracture space of lateral humeral fractures in children were significantly smaller than that of MRI measurements ($P<0.05$), confirming that X-ray measurement of the displacement distance of lateral humeral fractures is unreliable as a standard for the assessment of indications for surgery. The degree of fracture displacement measured on MRI tomographic images is more accurate, which can be beneficial to the selection of clinical treatment decisions.

The MRI is superior to X-ray in the diagnosis of pediatric humeral epicondylar fracture stability and evaluation of fracture displacement. Moreover, 3d-fs-fspgr or 3d-fspgr is the best MR sequence for the demonstration of pediatric humeral epicondylar fracture, providing a theoretical basis for the establishment of the clinical treatment plan.

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