CLINICAL ARTICLE

The Integrity of Cartilage Hinge in Song 2/3 Lateral Humeral Condylar Fractures in Children: A Retrospective Radiological Study in Two Centers

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Objective: For pediatric lateral condylar fractures (LCFs) of the humerus, it is often hard to determine the stability of the fracture based on the Song classification, especially for those categorized as Song stages 2 and 3. This study aims to define the characteristics of cartilage injury and assess the stability of LCFs classified as Song stages 2 and 3 on post-traumatic magnetic resonance imaging (MRI).

Methods: This was a retrospective study based on imaging data, conducted with a short follow-up period. From January 2016 to May 2019, data of all patients with Song 2 and Song 3 LCFs treated at two institutions were collected. Based on the inclusion criteria, a total of 62 patients with Song stage 2/3 LCF were included. All radiographs were selected for observation and classification for comparison by two observers, both experienced pediatric orthopedic surgeons. MRIs scans for comparison were analyzed in three consecutive coronal sections and cross-sections. Patients were treated conservatively with casting or surgically with closed reduction and percutaneous pinning (CRPP).

Results: Altogether 62 cases between 1.5 to 9 years old were included. Reliability analysis revealed poor, moderate, or good agreement between the two observers (range, 0.149–0.633). Both observers showed moderate or good consistency (range, 0.413–0.611). Among the 62 patients diagnosed with Song stages 2 and 3 fractures on initial radiographs, only two patients (3%) had complete fractures with complete disruption of the cartilage hinge as seen on MRI. The hinge was generally located in the posterior-inferior region of the distal humeral cartilage as indicated on MRI. There was no significant difference between Song stages 2 and 3 with regard to ratio of hinge to total values in any cross-sections, nor was there any significant difference in the completeness of the coronal sections ($P > 0.05$). Of the 62 patients treated, 50 were managed conservatively with casting and 12 underwent CRPP. Forty-nine of the remaining 60 patients (97%) with incomplete fractures were managed conservatively, while the remaining 11 patients were managed with CRPP. All patients with incomplete fractures showed bone healing and no evidence of lateral condyle displacement on follow-up radiographs.

Conclusions: The Song stage 2 or 3 classification is not entirely accurate and is inadequate at guiding treatment outcomes. The cartilage hinge was most likely located posteroinferiorly within the distal humeral epiphysis. According to our findings, conservative treatment with an effective cast or splint may be sufficient for bone healing in case of incomplete cartilage fractures.

Key words: Cartilage hinge; Humerus; Lateral condylar fracture; Magnetic resonance imaging; Stability

Introduction

Lateral condylar fracture (LCF) of the distal humerus is the second most common pediatric fracture involving the elbow. It accounts for approximately 12% of all pediatric elbow fractures and is usually prevalent between the ages of 6 and 10 years.[1,2] The optimal treatment for minimally displaced LCF is, however, subject to controversy.[3,4] The choice between operative and conservative treatment depends on the congruity of the articular surface.[5–11] However, the congruity of the articular surface cannot be easily assessed based on plain radiographs because there is a thick layer of cartilage beneath the distal humerus that cannot be visualized on radiographic films; additionally, the displacement of bony structures on radiographs do not always reflect cartilage displacement.[12]

Accordingly, many classification systems have been developed to predict the integrity of the articular surface, thereby allowing identification of patients who require operative treatment.[8,10,13] In 1975, Jakob *et al.* classified LCF in relation to the extent of fracture displacement, and this system has been widely used until today.[14] However, the Jakob classification cannot accurately determine whether the cartilage hinge is broken, and Jakob type II includes a wide range of circumstances that cannot be comprehensively treated with a single operative or nonoperative option. In 2008, Song *et al.* described a new classification system to determine the integrity of the cartilage layer based on the shape of the fracture line.[6] In theory, the five Song stages are categorically distinct from each other, with Song stage 2 classified as indefinable (intact cartilage hinge) and Song stage 3 as unstable (broken cartilage hinge). In clinical practice, however, it is very difficult to distinguish between these two stages. A response to this problem is the use of magnetic resonance imaging (MRI) to evaluate the integrity of cartilage,[15–17] which is an objective and reliable method in determining the integrity of the cartilage hinge and the stability of LCF.

This study aimed to describe the MRI appearance of LCFs classified as Song stages 2 and 3. We intended to ascertain: (i) whether the Song stages 2 and 3 could accurately assess the integrity of the cartilage hinge; (ii) whether the integrity of the cartilage hinge could guide clinical decision-making in selecting conservative or surgical treatment; and (iii) the short-term outcomes of such a strategy.

Materials and Methods

Ethics Consideration

All research procedures were approved by the Ethics Committee of the Shengjing Hospital of China Medical University (2020PS706K). This study was conducted in accordance with the principles of the Declaration of Helsinki for human subjects. The parents or legal guardians of the patients provided written informed consent before participating in this study.

Data Collection and Classification

From January 2016 to May 2019, the data of all patients with LCF, treated at two institutions, were collected. Patient inclusion criteria comprised the following: (i) the patient presented with a recent LCF (<1 week after injury); (ii) the patient had anteroposterior (AP) and internal oblique radiographs, as well as MRI scan of the elbow taken before treatment; (iii) radiographs showed stage2 and/or stage 3 fractures according to the Song classification system;[5] and (iv) all imaging data until the removal of cast could be collected. Data were excluded if the patient had: (i) an accompanying injury of the ipsilateral upper limb; (ii) systematic
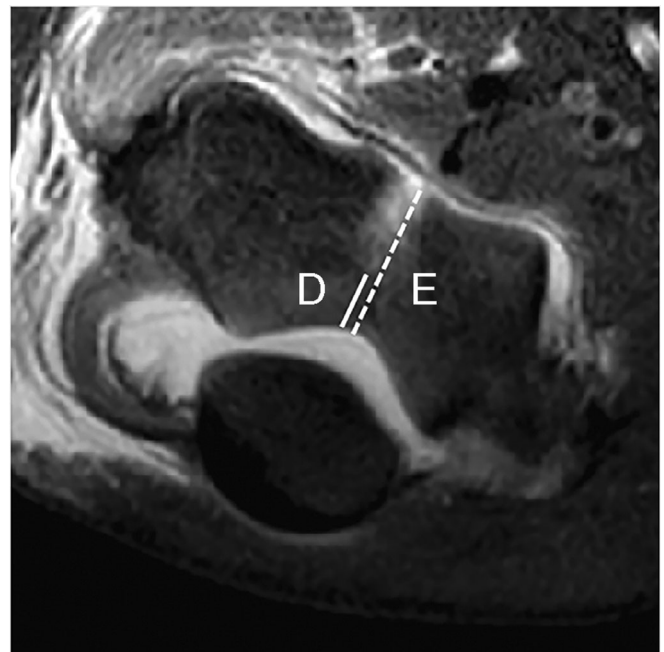

Fig. 1 Measurements used to determine the ratio of hinge to total (RHT). Line D, the width of the cartilage hinge; line E, the total width of the distal humeral epiphysis at the fracture site; RHT, divide the length of line E by that of line D

TABLE 1 Intra-observer and inter-observer reliabilities of the Song classification						
Observers	LTJ1	LTJ2	LTJ3	WEB1	WEB2	WEB3
LTJ1	1	0.467	0.611	0.423	0.289	0.439
LTJ2		1	0.595	0.425	0.149	0.289
LTJ3			1	0.633	0.203	0.460
WEB1				1	0.413	0.600
WEB2					1	0.524
WEB3						1

Notes: The boxes highlighted in gray are the intra-observer scores. LTJ and WEB were two independent observers.

diseases that might affect the musculoskeletal system; and (iii) unqualified or missing radiographic or MRI data.

Inter-observer and Intra-observer Reliabilities

All images were selected for observation and classification by two independent senior pediatric orthopedic surgeons. Both observers were familiar with the Song classification system before commencing the study. The observers assessed the radiographs independently of each other and assigned each anonymous patient to Song stage 2 or 3. They were asked to review the same radiographs 4 weeks later in a different order and classify them once again. This was repeated another 4 weeks later in the same manner. The final result was determined by a third senior orthopedic surgeon whenever the two surgeons held conflicting opinions.

MRI Studies

Elbow MRI was performed using a 3.0-T system (Ingenia CX; Phillips, Amsterdam, the Netherlands). All patients were scanned within 1 week of injury. All patients were positioned for MRI examination with the forearm in a neutral position and the elbow flexed at 30°–70°. Children under 5 years of age were sedated with 1 ml/kg chloral hydrate. Coronal T2-weighted, proton density with fat saturation and axialT2-weighted sequences were used with a 3–4-mm slice. We then calculated the ratio of the width of the cartilage hinge (the remaining intact part of the distal humeral epiphyseal cartilage) to the total width of the distal humeral epiphysis at the fracture site (ratio of hinge to total, RHT) in three consecutive cross-sections (Fig. 1). The three cross-sections were described as low, middle, and high. The lower section refers to the area closest to the articular surface. The middle section refers to the section containing or closest to the epiphyseal center, and the high section refers to the section closest to the epiphyseal line. If the fracture did not involve the cartilage, RHT was 1; if the cartilage was completely fractured, RHT was 0.

In the coronal plane, the three sections were described as anterior, middle, and posterior according to the sequence from the ventral side to the dorsal side. The anterior section was defined as the first image that could include the

TABLE 3 Cartilage integrity in three consecutive sections on coronal views

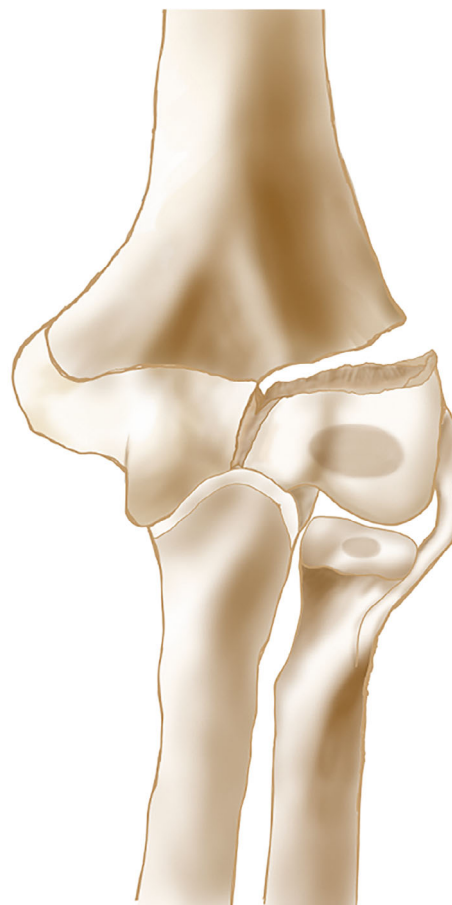| Sections	Song 2 (n = 51)	Song 3 (n = 11)	Total (n = 62)
Anterior	55% (28)	45% (5)	55% (34)
Middle	84% (43)	63% (7)	81% (50)
Posterior	96% (49)	100% (11)	97% (60)

Fig. 2 Illustration of an incomplete lateral condylar fracture of the humerus with an intact inferoposterior cartilaginous hinge

TABLE 2 RHTs in patients with Song stage 2 and 3 fractures (mean and range)

RHT	SONG 2 (n = 51)	SONG 3 (n = 11)	Total (n = 62)	P value
Low (SD; range)	0.78 (0.29; 0–1)	0.72 (0.27; 0.25–1)	0.77 (0.29; 0–1)*	0.59
Middle (SD; range)	0.62 (0.29; 0–1)	0.64 (0.24; 0.25–1)	0.62 (0.28; 0–1)**	0.82
High (SD; range)	0.28 (0.27; 0–1)	0.22 (0.30; 0–1)	0.26 (0.27; 0–1)***	0.58
F value	42.65	10.59	53.63	
P value	0.000	0.000	0.000	

Abbreviation: RHT, ratio of hinge to total.; *Notes:* * $p < 0.05$ (low RHT vs middle RHT).; ** $p < 0.05$ (middle RHT vs high RHT).; *** $p < 0.05$ (low RHT vs high RHT). p indicates comparisons between the Song 2 and Song 3 groups at the same level.; P shows the results of ANOVA among the three levels in Song 2, Song 3, and total groups.

entire distal humeral cartilage, and the consecutive two images were defined as the middle and posterior sections. RHT was not measured in the coronal plane because of the difficulty in defining the width of the epiphyseal cartilage in this view. The fractures were recorded as complete or incomplete. If any one of the sections showed an incomplete fracture, the case was regarded as incomplete. When all sections showed a complete fracture, the case was regarded as complete.

Treatment

Treatment was suggested based on the MRI findings. When an incomplete cartilage fracture was confirmed, conservative treatment with a cast or splint was suggested. These patients were reviewed after 2 and 5 weeks, respectively. The cast or splint was only removed after healing was confirmed. When the cartilage was completely broken, reduction and percutaneous pinning were suggested. Closed reduction was attempted first, and if it failed, open reduction was performed. The patients treated operatively returned to the hospital 4–6 weeks after surgery. The exact time depended on the intraoperative assessment of fracture stability. The casts and pins were removed when healing was confirmed.

Statistical Analysis

Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS 17.0, Chicago, IL, USA). Continuous variables are presented as mean ± standard deviation. Inter-observer and intra-observer reliabilities are presented as the k value. The k values were interpreted as follows: below 0.20 was poor agreement, 0.21–0.40 was fair, 0.41–0.60 was moderate, 0.61–0.80 was good, and over 0.80 was very good agreement. An independent samples t-test was performed to explore the differences between the treatment groups. Statistical significance was set at a P-value of <0.05.

Results

General Data

A total of 62 patients with Song stages 2 and 3 LCFs were finally included. Forty patients were treated in the Shengjing Hospital of China Medical University and 22 were treated in the Children's hospital of Anhui Medical University. There were 43 boys (69%) and 19 girls (31%), with a mean age of 4.5 years (range: 18 months to 9 years). Thirty-two patients (52%) had fractures in the left elbow and 30 (48%) in the
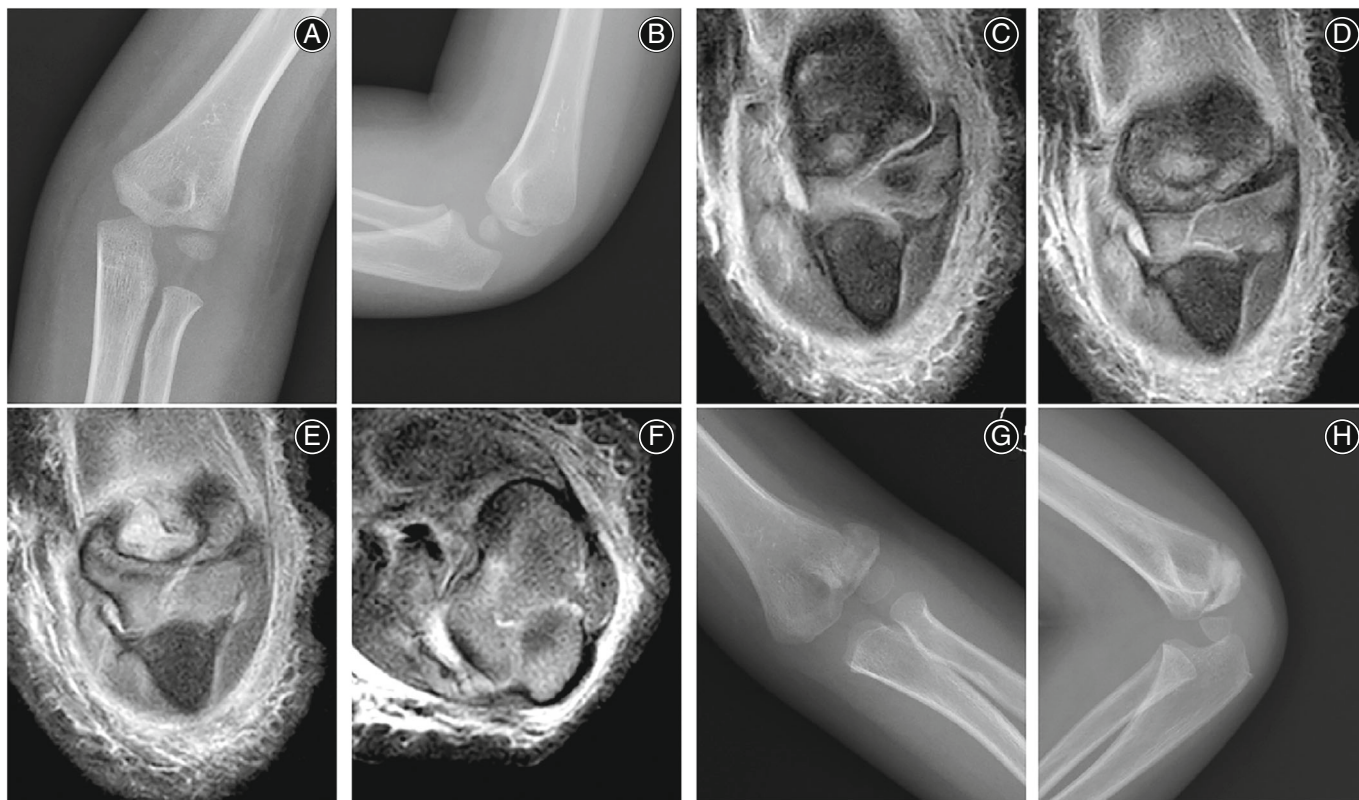

Fig. 3 Patient 4. (A) Antero-posterior and (B) internal oblique view of patient no. 4 with a Song stage 2 lateral condylar fracture (LCF); (C–F) magnetic resonance imaging (MRI) showing complete cartilage fracture in the anterior, median and posterior plane, indicating a complete cartilage fracture; (G, H) This patient refused operative treatment and selected nonoperative management with a cast. Ten weeks after treatment, the fracture is still slightly displaced upwardly. Abundant callus formation is noted, but the fracture line is still visible

right elbow. Fifty patients were treated conservatively and 12 underwent surgery. The average follow-up duration was 51 days (range: 30–153 days). All fractures healed uneventfully. Reliability analysis revealed poor, moderate, or good agreement between the two observers (range, 0.149–0.633), and the two observers individually showed moderate or good consistency (range, 0.413–0.611) (Table 1).

MRI and Cartilage Hinge

Among the 62 patients diagnosed with Song stage 2 or 3 fracture on the initial radiographs, only two patients (3%) had a complete fracture with complete disruption of the cartilage hinge as seen on MRI (fractured cartilage on all coronal sections and cross-sections). Subsequently, the two observers were requested to divide the 62 patients into either Song stage 2 or 3 based on radiographic findings. Fifty-one patients were assigned to stage 2 fractures and 11 to stage 3 fractures, respectively. Interestingly, the two previously MRI-diagnosed cases of complete cartilage fracture and disruption were classified into Song stage 2 by both observers in this current study.

In the MRI cross-sections, RHT data revealed that the lower the section, the higher the extent of integrity (Table 2). This indicated that the cartilage hinge was most likely intact in the inferior region. The gap between the fracture ends was widest in the superior region, subsequently decreasing as the fracture line extended downward. Similarly, the anterior cartilage was completely fractured in approximately half of the cases, but almost all posterior cartilages maintained some connection (Table 3). This indicated that the cartilage hinge was most likely to be still intact in the posterior region. In summary, the cartilage hinge is generally located in a region that is the least likely to be affected by a fracture, in the posterior-inferior region of the distal humeral cartilage (Figure 2). There was no significant difference between Song stages 2 and 3 concerning the RHT values in all cross-sections, nor was there any significant difference in the completeness of the coronal sections ($P > 0.05$).

Treatment and Outcomes

Of the 62 patients treated, 50 were managed conservatively and 12 received closed reduction and percutaneous pinning (CRPP). One of the two patients with complete fractures received CRPP treatment and had good bone union. The other patient rejected the CRPP treatment option and selected conservative treatment with a cast. The patient consequently had delayed union and minimal displacement (Fig. 3). Forty-nine of the remaining 60 patients (97%) who had incomplete fractures (Fig. 4) were managed conservatively, whereas the remaining 11 patients were managed with
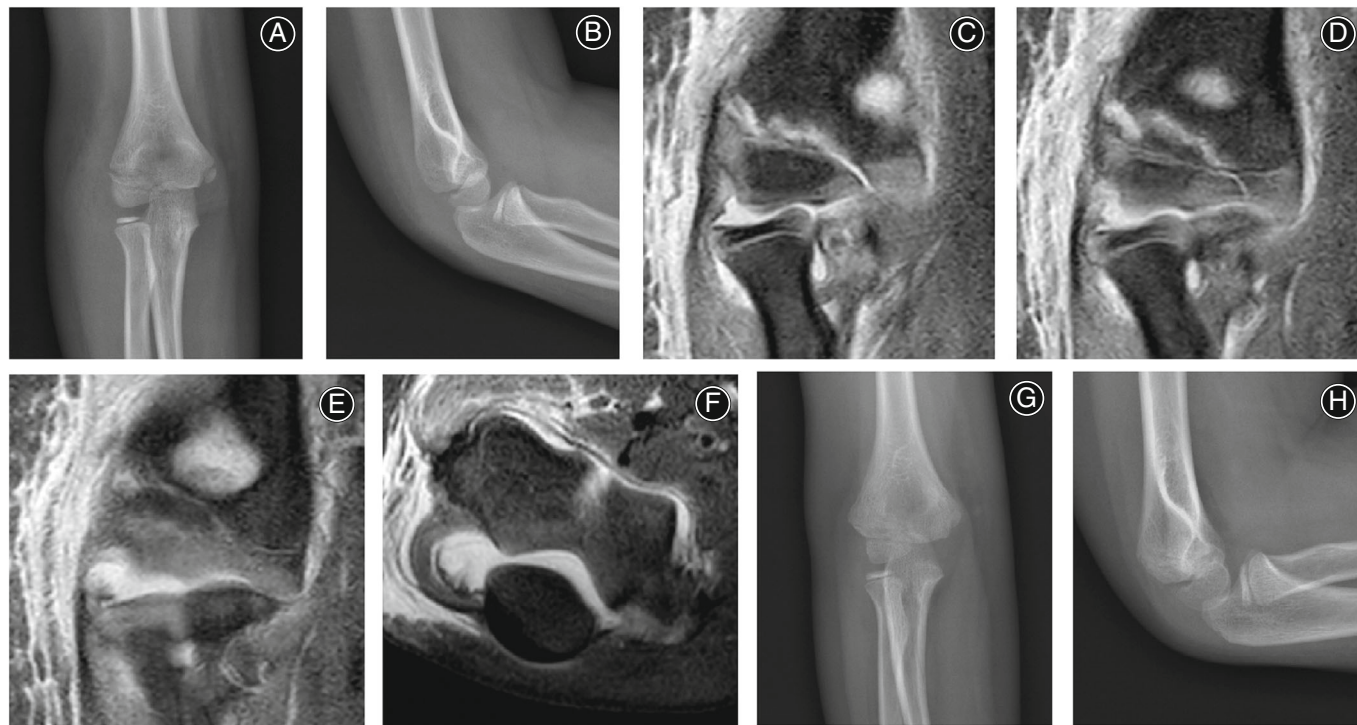

Fig. 4 Patient 29. (A) Antero-posterior and (B) lateral view of patient 29 with a Song stage 3 lateral condylar fracture (LCF); (C, D) magnetic resonance imaging (MRI) showing complete cartilage fracture in the anterior and median plane; (E, F) MRI of the posterior coronal section and the transverse plane showing the cartilage is still partially connected; (G, H) This patient was treated conservatively with a cast. Six weeks after treatment, radiographs show a blurred fracture line and non-displaced fracture

CRPP. All patients with incomplete fractures displayed bone healing without evidence of lateral condyle displacement on follow-up radiographs.

Discussion

A critical issue in the treatment of LCFs of the humerus is the assessment of fracture stability. Conservative treatment yields satisfactory outcomes when the fracture is considered stable. However, when an unstable fracture is treated conservatively, there is a high risk of complications, including displacement, delayed union, and non-union.[2] The stability of an LCF is determined based on the integrity of the distal humeral cartilage. If the cartilage is completely damaged, the fracture is unstable and easily displaced. If the cartilage is at least still partly attached, specifically at the cartilage hinge, the fracture is largely stable and has a great chance to heal uneventfully with conservative treatment through casting.

Song Stage 2/3 Does Not Indicate Cartilage Integrity

Displacement between the bony articulations may be indicative of cartilage integrity, as described in the Jakob classification system.[13] However, the degree of bone displacement is difficult to ascertain in minimally displaced LCFs. The Song classification, which was first reported in 2008, attempts to assess cartilage integrity according to the morphology of the fracture gap.[6] Song stage 2 refers to a lateral gap below 2 mm in all four radiograph views (anteroposterior, lateral, internal, and external oblique views), with indistinct instability. Song stage 3 refers to a gap below 2 mm, which is as wide laterally as medially, in any of the four radiograph views and was classified as unstable. Although the Song classification has been reported to have good overall inter-observer and intra-observer reliabilities,[6] in our study, differentiating Song stage 2 from stage 3 was challenging, with moderate inter-observer and intra-observer reliabilities.

Apart from the ambiguity in defining the lateral and medial widths of the gap, there are other underlying mechanisms responsible for this difficulty. When compared with MRI images, we found that stages 2 and 3 of the Song classification system do not accurately reflect the integrity of the cartilage. There were marked inconsistencies between the findings clearly observed on MRI and the Song ratings for radiographs. The cartilage was not completely broken in the majority of the stage 3 cases, whereas the two cases with complete cartilage fractures were classified as stage 2 by both study observers. Some studies report that most of the cases classified as Song 3 had incomplete cartilage fractures. Haillotte et al. found 10 incomplete fractures and four complete fractures in 14 patients with minimally displaced fractures of the lateral humeral condyle.[16] Kamegaya et al. found seven incomplete fractures in 12 patients with minimally displaced LCF.[18] Despite minimally displaced findings in Song 3 cases, all cases classified into Song stage 3 are deemed unstable and are routinely treated with internal fixation, resulting in overtreatment.

MRI can provide good three-dimensional observations of LCF.[15–18] Previous studies have defined complete LCF fractures as those showing extension of the fracture through the cartilaginous epiphysis into the elbow joint, indicating disruption of the cartilage hinge, using only one MRI coronal section for assessment.[16–18] In our study, we assessed the cartilage hinge integrity through three coronal sections and three cross-sections; multiple MRI views provide a more complete three-dimensional observation of the cartilage of the distal humerus. By combining the findings in the coronal sections and cross-sections, we found that the fracture gap of LCF was widest in the anterior-superior part of the fracture line. The gap decreased as the fracture extended backward and downward. To the best of our knowledge, within the literature, this is the first study that has established that in most cases of Song stages 2 and 3, the elbow cartilage remained intact posteriorly and inferiorly, functioning as a hinge to maintain the stability of the fracture. The morphology of the gap in radiographic films does not actually reflect the integrity of the cartilage because the varied presentations of this three-dimensional feature are lost when projected onto a two-dimensional radiographic fracture line.

Treatment based on Cartilage Integrity and Short-term Follow-up

In our study, treatment was mostly designed based on the MRI findings. For patients with an incomplete cartilage fracture, simple fixation with a well-molded cast or splint can achieve a satisfactory outcome, with healing completed no later than those treated with CRPP. In one case with a complete fracture, CRPP was successful, resulting in complete healing. However, for another patient with a complete fracture who chose conservative treatment, healing was delayed with minimal displacement. These cases confirmed the practicability of our treatment regimen using fixation to treat complete fractures to avoid displacement or delayed union. However, the number of cases we treated were still too small to formalize this routine.

Limitation

The main limitation of this study was its retrospective nature. Although this is the largest study, to date, on the MRI characteristics of Song stage 2 and 3 fractures, the number of complete fractures was so limited that no further comparison could be made. Additionally, treatment was conducted by four different surgeons, as requested by the patients themselves, a few of whom did not follow our suggestions. However, the majority of patients whose cartilage hinges were intact still had good results with conservative management.

Conclusion

Overall, the Song stages 2 and 3 classification is not entirely accurate and may not be adequate to guide management in LCFs. The integrity of the elbow cartilage was not considered in the Song classification. MRIs can

accurately determine stability and guide the management of LCFs. The cartilage hinge was most likely located posteriorly within the distal humeral epiphysis. For cases of incomplete cartilage fractures, conservative treatment with an effective cast or splint is probably sufficient for bone healing in LCFs.

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