Ultrasound Versus Arthrography in Diagnosing the Stability of Minimally Displaced Lateral Humeral Condyle Fractures in Children

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Research article

Keywords: Ultrasound, Arthrography, Lateral condyle fractures, Children

DOI: https://doi.org/10.21203/rs.3.rs-61559/v1

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Abstract

Background: The evaluation of the articular cartilage status of the distal humeral epiphysis is difficult. Ultrasound of the elbow is increasingly used to confirm the integrity of the articular cartilage of minimally displaced lateral humeral condyle fractures in children in minimally displaced fractures. The aim of this study was to assess the correlation between ultrasound with arthrography for predicting the integrity of the cartilage hinge and describe the utility of ultrasound in directing the need for pre-treatment.

Methods: 39 patients with minimally displaced lateral humeral condyle fractures and underwent ultrasound and arthrography examinations before operation from May 2018 to December 2019 were included in this study. The ultrasound and arthrography predictors of the cartilage hinge status were independently measured. Result of ultrasound and arthrography were compared.

Results: The mean displacement of fractures was 3.1 mm (range, 2.0–5.0 cm). The arthrography showed an incomplete fracture in 24 patients (61.5%) and complete in 15 patients (38.5%). The ultrasound showed an incomplete fracture in 25 patients (64.1%) and complete in 14 patients (35.9%). The ultrasound and arthrography evaluations of the integrity of the articular surface were consistent in 92.3% of the cases, including 23 were predicted to have an intact articular surface, and 13 were predicted to have incongruity articular surface. There was no correlation between displacement and the fracture being complete on ultrasound. The Pearson coefficient value of ultrasound and arthrography for assessing the integrity of the articular surface was 0.837.

Conclusions: Ultrasound and arthrography assessments of the integrity of the cartilage hinge status appear to be highly consistent. Ultrasound can be used as a complementary tool with arthrography to predict the integrity of the cartilage hinge status of patients with minimally displaced lateral humeral condyle fractures in children.

Level of evidence: Retrospective study; level IV.

Background

Lateral humeral condyle fractures (LHCF) is the second most common elbow fracture in children, makeup 12–20% of elbow fractures[1, 2]. According to published guidelines, the indication of treatment is driven by the displacement and stability of the fracture. It is still controversial whether it is necessary to open reduction and internal fixation (ORIF) for minimally displaced LHCF with an incongruent articular surface. ORIF may be associated with complications, including avascular necrosis, premature physeal closure, non-union, arthrofibrosis, infection, wound scar, and refracture[3, 4]. Closed reduction and percutaneous pinning (CRPP) is a safe and effective alternative to minimally displaced LHCF with an intact articular surface[4, 5].

The integrity of the articular cartilage of the distal humeral epiphysis determines the stability of LHCF[6]. If the cartilage of the hinge is not intact, the fracture is complete, and the injury is unstable and predisposed to further displacement. Standard radiography has limitations in showing the epiphyseal cartilage of the distal humerus in children. Magnetic resonance imaging (MRI)[7, 8] or arthroscopy[9, 10] can detect the integrity of
the articular cartilage, and the former requires sedation, it is difficult for children to cooperate with the examination, the later requires general anesthesia. Arthrography is mainly used to detect the integrity of the articular cartilage for this fracture[11]. However, arthrography also requires sedation and may lead to invasive infections. Therefore, it is exceedingly essential to evaluate the articular cartilage status before treatment. Recently, ultrasound provides a valuable examination to assess the stability of the fracture[12–14]. However, no data exist on the correlation between arthrography and ultrasound in judging the integrity of articular cartilage with minimally displaced fractures.

The purpose of this study is to assess the correlation between ultrasound with arthrography for predicting the integrity of the cartilage hinge and describe the utility of ultrasound in directing the need for pre-treatment in the minimally displaced LHCF in children.

**Methods**

The Institutional Review Board approved this prospective study, and patients and their parents gave informed consent. Patients with a diagnosis of minimally displaced LHCF (2–5 mm) between May 2018 and December 2019 participated in the study. Patients with open injury or multiple injuries, fractures with displacement measuring over 5 mm were excluded. All cases underwent reduction and fixation under general anesthesia. Ultrasound and arthrography were performed before reduction. The results of the ultrasound and arthrography analyses were considered separately, and the experts were blinded to each other's results.

The study was designed that all patients underwent ultrasound first. GE LOGIQ e ultrasound system (GE Healthcare, Milwaukee, WI, USA) equipped with 7.0-12.5 MHz linear array transducer (GE Healthcare, Tokyo). Ultrasound examinations and analyses were conducted by one pediatric orthopedic surgeons with experience in osteosonography diagnosis in children. Ultrasonographic imaging of the distal humerus was performed and documented in five standardized sectional planes: (1) ventral-radial, (2) ventral-median, (3) dorsal-radial, (4) lateral, (5) anterior transversal[12, 13, 15]. The integrity of articular cartilage at the distal humeral epiphysis was determined on anterior transversal view. According to our previous description[13], the intact articular surface is defined as those in which the fracture line limited to the articular cartilage, the articular cartilage of the distal humeral is continuous(Fig 1). An incongruent articular surface is defined as those in which the fracture line extends through the cartilaginous epiphysis into the elbow joint, the articular cartilage is displaced, and the hyperechoic gap can be seen(Fig 2).

An arthrography[11] was performed after the ultrasound. Arthrography was achieved by directly posterior puncturing the contrast dye into the elbow joint[16]. The images were augered by an experienced pediatric orthopedic surgeon (S.X.T), who were blinded to the ultrasound results. The integrity of the cartilage hinge of the distal humerus was independently measured on radiograph and ultrasound images by two observers. Repeated assessments for the elbow fracture maintained an interrater correlation coefficient higher than 0.8.

If the fracture reduction was confirmed to be within 2 mm, CRPP was performed. If the fracture reduction could not reduce the displacement to within 2 mm, ORIF should be performed. A long-arm cast was applied in all cases, and the pins were removed four to six weeks after surgery.
Statistical analysis

For the descriptive analysis, percentages were calculated for the categorical variables and averages for the quantitative variables. Spearman correlation coefficient was used to analyze the relationship between fracture displacement and the integrity of the articular surface and the relationship between ultrasound and arthrography measurements. P < 0.05 was considered statistically significant. The statistical analysis was performed with SPSS version 19.0 software package (IBM Corporation, Armonk, NY).

Results

The study enrolled 39 patients who averaged age of 53.9 months (range, 18–102 months). There were 27 boys and 12 girls. There were 22 left and 17 right. As measured by initial radiographs, the mean displacement of fractures was 3.1 mm (range, 2.0–5.0 cm). The results are shown in Table 1.

The operation had performed an average of 2.7 days (range, 1–5 days) after the fracture. The arthrography analysis was done on all patients. The fracture was incomplete in 24 patients (61.5%) and complete in 15 patients (38.5%). There was a correlation between the displacement and fracture being complete (p < 0.05). The ultrasound was taken an average time of 3 minutes. The fracture was incomplete in 25 patients (64.1%) and complete in 14 patients (35.9%). There was no correlation between displacement and the fracture being complete (p > 0.05).

The ultrasound and arthrography predicted the same outcomes for the integrity of the articular surface in 36 (92.3%) of the 39 patients; among these 36 patients, 23 were predicted to have intact articular surface, and 13 were predicted to have incongruity articular surface. The correlation coefficient value of these imaging modalities was 0.837 (p < 0.05). Of the three patients with > 4 mm of fracture displacement, one was found to have an incomplete articular surface, and two were found to have a complete articular surface.

Among the three patients with different prediction results, the NO.3 patient with displacement of 2.4 mm predicted intact articular surface by ultrasound, but incongruity articular surface by arthrography. The NO.5 patient with a displacement of 3.9 mm predicted incongruity articular surface by ultrasound but intact articular surface by arthrography. The NO.35 patient with a displacement of 3.4 mm predicted congruity articular surface by ultrasound but incongruity articular surface by arthrography.

All cases were treated with CRPP. Fracture union was achieved, at which point the cast was removed. There were no cases of non-union.

Discussion

LHCF is an intra-articular fracture. The integrity of the articular cartilage is an essential factor in predicting the stability of the fracture. In our study, both ultrasound and arthrography assess the highly consistent of the preoperative integrity of the articular cartilage status. Compared with arthrography, ultrasound was efficient in determining the integrity of the articular cartilage with noninvasive, no ionizing radiation, and
more convenient. Ultrasound can be used as a complementary tool with arthrography to predict the integrity of the articular cartilage status of patients with minimally displaced LHCF.

The recent Song’s[17] and Weiss’s[3] classification are based on the integrity of the articular cartilage surface. Because the distal humeral epiphysis is not ossified, the cartilage of the distal humerus could not be detected by radiography. Therefore, there is a controversy between the integrity of the articular cartilage status and the classification of the radiograph. Ultrasound is a reliable, non-ionizing radiation, low-cost, noninvasive technique that does not require sedation or general anesthesia, especially for pediatric elbow examination[12–15, 18]. Previous study had shown that transverse ultrasound could be used to detect whether the fracture was complete or incomplete[13]. Vocke-Hell et al[12] found that ultrasound could show the fracture line extends through the articular cartilage in the transversal view. If the hypoechoic cartilage hinge is disrupted and the hyperechoic fracture line extends to the distal humeral articular cartilage, it is determined to be a complete LHCF. If the hypoechoic articular cartilage hinge is smooth and continuous, it is judged to be incomplete LHCF. Our study showed that the ability of arthrography to predict the integrity of the articular surface involvement was powerful, and ultrasound had high diagnostic value in predicting the integrity of the articular surface status, but the former has less invasive and no radiative exposure.

In our study, even if the displacement of the fracture was ≥ 2 mm, 64.1% of minimally displaced LHCF were intact articular surface. Similar to the previous reports[3, 6, 8, 19], the fractures displaced < 4 mm on radiographs were more likely to be intact articular surface. However, no fractures with ≥ 4 mm of displacement were performed arthrography in Weiss’s data. Song et al[17] found that all patients with incongruent articular surface fractures displaced > 2 mm on radiographs. But, the integrity of the cartilage hinge status of Song’s data was mainly determined on the basis of the internal oblique radiograph. Although there was a statistically significant correlation between arthrography assessments and fracture displacement, this correlation was not found on ultrasound. It is difficult to assess the relationship between the displacement of the fracture and the integrity of the cartilage hinge status. Especially, there were only three patients with > 4 mm of fracture displacement in this series. We could not find the relationship between fractures with > 4 mm of displacement and the integrity of the articular surface from our data. However, this 4 mm cut-off was not a clinical criterion prospectively used for assessment of the incongruity articular surface. In addition, compared with the displacement of the fracture, the routine use of ultrasound was more effective in the evaluation of the cartilage hinge status before the initial treatment of these fractures.

There were three patients predicted to have controversial integrity of the articular surface between ultrasound and arthrography. Ultrasound can observe the hypoechoic layer of the hyaline articular cartilage in the distal humeral epiphysis. The fracture line is directly found by the hyperechoic gap and disrupted of the hypoechoic layer on the anterior articular surface[12]. Arthrography is a reference standard for predicting the integrity of the articular cartilage surface[3, 11, 20]. However, arthrography indirectly detects the integrity of the articular surface of the distal humerus through contrast medium tracking. For the complex three-dimensional articular cartilage fractures, it is difficult to judge by arthrography. In addition, radiation
exposure exists in arthrography, which requires sedation or anesthesia, and false-negative results[11]. On the basis of Pennock[19] data, they considered arthrography is unclear to confirm the congruency of the articular surface. Although this study has not been further confirmed those differences, on the base of our data, we believe that ultrasound can provide more accurate information to determine the integrity of the articular cartilage.

In our study, CRPP was achieved in all patients, and no major complications occurred. As previously reported in the literature, it is controversial whether minimally displaced LHCF was treated with ORIF or CRPP. The displaced LHCF with displacement > 1 mm has been treated with ORIF to avoid re-displacement and non-union, enabling direct visualization of the articular surface to confirm anatomical reduction[21, 22]. Because the articular surface was intact in most cases with a displacement of ≤ 4 mm confirmed by arthrography, those fractures were recently treated safely used CRPP, and no major complications were reported[3, 19, 23]. Song et al[17, 24] expanded the indications of CRPP to all fracture with incongruent articular surface or fracture displacement > 2 mm with a close reduction success rate of 73% (46/63). Even in case NO.24 (Fig. 1) was displaced 5 mm on internal oblique radiographs. Intact articular cartilage was confirmed by ultrasound. Based on the existence of cartilage hinges, the fracture can easily be achieved close reduced like a door hinge switch by overstretching and valgus of the elbow joint. Therefore, we recommend that CRPP is introduced in the treatment of LHCF with minimal displacement, especially in the case with an intact articular surface.

There are some limitations to our study. First, although this was the largest study on this topic published up to now, the sample size is still small. Our results clearly show that ultrasound and arthrography were consistent in predicting the integrity of cartilage hinges of patients with min-displaced LHCF in children. We believed that our results could be generalizable to other clinicians with focused ultrasound. Second, an inherent limitation of this study was that arthrography refers to the diagnostic criteria of ultrasound in predicting the integrity of the cartilage hinge and the stability of the fracture. In fact, whether arthrography itself meets the diagnostic criteria has not yet been reported. We performed arthrography for all fractures as a standard. However, it is not known whether there was a potential complete fracture. Recently, we have begun trying to use preoperative MRI and ultrasound to better assess the integrity of the articular surface of the fracture in further research.

**Conclusion**

This report confirmed ultrasound plays an important role in the diagnosis and treatment of fractures in children. A significant correlation was found between ultrasound and arthrography in measuring the fracture of articular cartilage in the distal humerus. In addition, compared with arthrography, ultrasound is more noninvasive, simple and effective. Ultrasound can be used as a complementary tool with arthrography for preoperative assessment of the integrity of the cartilage hinge status of patients with minimally displaced LHCF in children.

**Abbreviations**
Lateral humeral condyle fractures; ORIF: Open reduction and internal fixation; CRPP: Closed reduction and percutaneous pinning; MRI: Magnetic resonance imaging

**Declarations**

**Ethics approval and consent to participate**

The Ethics Committee of Wuhan children's hospital (No.2020R012) gave a final approval for this study. Although the data were collected anonymized and centrally, all guardians of patients signed written informed consent for participate.

**Consent for publication**

All guardians of patients signed written informed consent for publication

**Availability of data and materials**

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

**Competing interests**

The authors declare that they have no competing interest.

**Funding**

This study was funded by project with Health and Family Planning Commission of Wuhan municipality (WX14C49) and Natural Science Foundation of Hubei Province (2013CKB026).

**Authors' contributions**

X.W, X.L, J.X, S.W, X.C and S.Y were involved in data collection and follow-up assessments. X.W and X.S were responsible for literature search and study design. X.W were responsible for drafting the manuscript. X.S and X.W. finalized the manuscript. All authors have read and approved the submitted manuscript.

**Acknowledgements**

Not applicable

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Tables

Table 1 Patient Demographic Data
| ID | Sex | Age(month) | Side | Radiographic displacement(mm) | Time to examination (d) | Integrity of cartilage hinge Arthrography | Integrity of cartilage hinge US |
|----|-----|------------|------|-------------------------------|-------------------------|-----------------------------------------|--------------------------------|
| 1  | Female | 32 | Right | 3.56 | 3 | I | I |
| 2  | Male | 52 | Right | 3.42 | 1 | I | I |
| 3  | Male | 52 | Left | 2.4 | 1 | I | D |
| 4  | Female | 72 | Right | 3.7 | 3 | D | D |
| 5  | Male | 75 | Left | 3.9 | 3 | D | I |
| 6  | Male | 49 | Right | 2.2 | 3 | I | I |
| 7  | Male | 80 | Right | 4 | 4 | D | D |
| 8  | Male | 85 | Left | 3.99 | 3 | D | D |
| 9  | Male | 30 | Right | 2.4 | 4 | I | I |
| 10 | Male | 24 | Right | 3.96 | 3 | I | I |
| 11 | Female | 21 | Left | 3.51 | 2 | I | I |
| 12 | Male | 42 | Right | 2 | 3 | I | I |
| 13 | Male | 38 | Right | 3.3 | 3 | I | I |
| 14 | Male | 36 | Left | 2.6 | 3 | D | D |
| 15 | Male | 93 | Left | 3.2 | 2 | I | I |
| 16 | Male | 56 | Left | 3.3 | 1 | D | D |
| 17 | Male | 55 | Right | 2.4 | 3 | I | I |
| 18 | Male | 64 | Left | 2.1 | 4 | I | I |
| 19 | Male | 92 | Left | 2.6 | 3 | I | I |
| 20 | Female | 85 | Left | 3.4 | 3 | D | D |
| 21 | Female | 49 | Left | 2.1 | 2 | D | D |
| 22 | Female | 18 | Left | 2.3 | 3 | I | I |
| 23 | Female | 24 | Right | 2.9 | 1 | I | I |
| 24 | Male | 18 | Right | 5 | 3 | I | I |
| 25 | Male | 38 | Right | 2.3 | 2 | I | I |
| 26 | Male | 36 | Left | 3.8 | 2 | D | D |
| 27 | Male | 93 | Right | 2.5 | 3 | I | I |
|   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|
| 28 | male | 55 | Left | 2.4 | 4 | I | I |
| 29 | female | 85 | Left | 3.3 | 2 | D | D |
| 30 | male | 102 | Left | 3 | 3 | D | D |
| 31 | female | 18 | Left | 2.5 | 2 | I | I |
| 32 | female | 24 | Right | 3.1 | 3 | I | I |
| 33 | male | 54 | Left | 2.6 | 1 | I | I |
| 34 | female | 32 | Left | 3.7 | 3 | D | D |
| 35 | male | 90 | Right | 3.4 | 3 | D | I |
| 36 | male | 82 | Left | 2.3 | 3 | I | I |
| 37 | male | 51 | Left | 2.4 | 3 | I | I |
| 38 | male | 43 | Right | 3.5 | 2 | D | D |
| 39 | female | 55 | Left | 4.2 | 4 | D | D |

I: intactness; D: disruption;

**Figures**
Figure 1

Patient in case 24. a, Radiographs of anteroposterior showed a displacement of 2.5mm. b, Radiographs of internal oblique showed a displacement of 5mm. c, Transverse ultrasound image showed the disrupted cartilage hinge on the lays when the center of ossification of capitellum epiphysis was found. d, Transverse ultrasound image showed the intact cartilage hinge before reaching the articular surface, disrupted cartilage hinge (arrow). e, Radiographs of anteroposterior views of an arthrogram, the dye was tracked along the fracture line and stops before reaching the articular surface (arrow), thus maintaining an intact cartilaginous hinge. arrowhead: cartilage hinge, asterisk: epiphyseal core of ossification of the capitellum, double asterisks: hemorrhage, M: medial, L: lateral, C: cartilage of epiphysis
Figure 2

Patient in case 4. a, b Radiographs of anteroposterior and internal oblique. c, Transverse ultrasound image showed the disrupted cartilage hinge, stair sign of large cartilage gap. d, Radiographs of anteroposterior views of an arthrogram, the dye tracking along the fracture line pass through the articular surface, thus maintaining an incongruity of articular surface. arrow: disrupted cartilage hinge, arrowhead: cartilage hinge, asterisk: epiphysial core of ossification of the capitellum, M: medial, L: lateral.