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Original article

A novel transverse ultrasonography technique for minimally displaced lateral humeral condyle fractures in children

Xiong-Tao Li , Xian-Tao Shen *, Xing Wu , Xiao-Liang Chen

Wuhan Children's Hospital, Tongji, Medical College, Huazhong University of Science & Technology, Wuhan City, PR China

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ABSTRACT

Introduction: Management of minimally displaced lateral humeral condyle fractures in pediatric patients is controversial. This is primarily because with current imaging modalities it is difficult to accurately and conveniently determine the stability of the fractures by detecting the integrity of the cartilage hinge. Nevertheless, transverse ultrasonography has not been intensively reported in previous studies.
Hypothesis: Transverse ultrasonography can determine the integrity of the cartilage hinge in minimally displaced lateral condyle fractures.
Materials and methods: We retrospectively reviewed the medical records of 39 pediatric patients with minimally displaced fractures of the lateral humeral condyle who underwent transverse ultrasonography between 2014 and 2017. Conservative treatment was given to pediatric patients with intact cartilage hinges that had been confirmed by transverse ultrasound images. Surgical treatment was recommended for pediatric patients with disrupted cartilage hinges. Data regarding healing of the lateral humeral condyle fractures were recorded and analyzed.
Results: According to transverse ultrasonography, there were 14 children with intact cartilage hinges and 25 children with disrupted cartilage hinges. Fourteen children with intact cartilage hinges of the fracture were treated conservatively, and none of them showed secondary displacement. There were 16 children in whom there was surgical intervention, and 9 other children decided to have conservative treatment among the 25 children with disruption of the cartilage hinge. Five of these 9 children who underwent conservative treatment were found to have further displacement during an average of 12.6 days after the fracture event, and no other patient was found to have further displacement.
Conclusion: Transverse ultrasonography can simply and accurately determine the stability of minimally displaced lateral condyle fractures without sedation, ionizing radiation or invasive techniques. We recommend routine use of transverse ultrasonography to detect stability of the fractures, which can effectively avoid inadequate treatment and unnecessary surgery in pediatric patients with minimally displaced fractures of the lateral humeral condyle.
Level of evidence: IV, retrospective cohort study.

1. Introduction

Lateral humeral condyle fractures (LHCF) are the second most common fracture of the elbow in children, accounting for 10% to 20% of pediatric distal humerus fractures [1,2]. There are various schemes for classifying LHCF in children. The most commonly used classification in clinical work classifies LHCF as nondisplaced (traditionally, < 2 mm), minimally displaced (traditionally, 2 to 4 mm), or displaced (traditionally, > 4 mm) [3–5]. There is consensus that displaced fractures require surgical treatment and nondisplaced fractures need conservative treatment. Nevertheless, the treatment of minimally displaced LHCF in pediatric patients remains controversial [6–8]. Conservative treatment of all fractures that present minimally displaced on radiographs can lead to up to 14.9% of patients having secondary displacement [9]. The risk of secondary displacement has resulted in some surgeons advocating for surgical treatment of all patients, although some patients do not need surgery to prevent potential complications [3,10,11].

In general, the integrity of the cartilage hinge at the distal humeral epiphysis determines the stability of minimally displaced LHCF. If the cartilage hinge of the fracture is intact, the fracture should be considered stable and only needs conservative treatment.

* Corresponding author. Wuhan Children's Hospital, Tongji Medical College, Huazhong University of Science & Technology, Orthopedics, 100 Hong-Kong Road, Jiang'an District, 430016 Wuhan City, PR China.
E-mail address: xiantaoshen9815@aliyun.com (X.-t. Shen).

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Conversely, if the cartilage hinge of the fracture is disrupted, the fracture should be considered unstable and the tendency to further displacement requires surgical treatment [12]. However, the cartilage hinge of the distal humeral epiphysis cannot be visualized on conventional plain films in pediatric patients [13,14].

Ultrasonography (US) can be performed to evaluate the cartilage hinge of the distal humeral epiphysis. Furthermore, compared with elbow arthrography or magnetic resonance imaging (MRI), US is more valuable as an examination that does not require sedation, radiation or invasive procedures [15,16]. However, conventional US is specialized and usually requires a trained radiologist to perform the procedure [17]. In our department, we adopted transverse ultrasound images over the anterior elbow to evaluate the integrity of the cartilage hinge. This improved method is simple and pediatric orthopedic surgeons can perform the procedure independently.

The hypothesis of this study is that transverse US can be used to determine the integrity of the cartilage hinge in minimally displaced LHCF, which could avoid inadequate treatment and unnecessary surgery in pediatric patients.

2. Materials and methods

2.1. Patients

This study was approved by institutional review board. The guardians of the children gave informed consent prior to the ultrasound examinations. There were 39 pediatric patients with minimally displaced LHCF who were included in this retrospective single-center study from January 2014 to December 2017. LHCF with minimal displacement were diagnosed by anteroposterior and lateral radiography according to Jakob classification in our emergency department[4]. The fractures combined with olecranon fractures, radial neck fractures and evidently fragment-rotated LHCF were excluded. All minimally displaced LHCF were subjected to assessment of the integrity of the cartilage hinge of distal humeral epiphysis by transverse ultrasonography. The transverse ultrasonography was performed in the orthopedic inpatient or outpatient department by a senior pediatric orthopedist in our hospital.

2.2. Methods

Transverse ultrasonography was performed with a GE Logic E9 ultrasound system (GE Healthcare, Milwaukee, WI, USA) and a high-frequency transducer of at 7.0–11.0 MHz (GE Healthcare). During the whole examination, the pediatric patients keep awake without sedation and painless, and the children can be accompanied and comforted by their parents. The examination of the anterior elbow can be completed with lying supine position of the child. The elbow is comfortably extended on an examination table, and the hand is supinated. Evaluation with the transducer occurred in the short axis of the articular cartilage hinge just superior to the elbow joint (Fig. 1). The hypoechoic layer over the hyperechoic cortex of distal humeral epiphysis is the hyaline articular cartilage hinge, and the brachialis and brachioradialis are separated by intermuscular septum above the cartilage hinge. If the articular cartilage hinge is intact, the articular cartilage of the distal humeral articular cartilage is smooth and continuous, similar to a "wave" in transverse ultrasound examinations (Fig. 2). If the cartilage hinge is disrupted, we can determine that the fracture line extends to the distal humeral articular cartilage. There is massive hemorrhage between the fracture fragments, and the articular cartilage is destroyed and displaced, just as the "stair sign" in the transverse ultrasound images (Fig. 3). During transverse ultrasonography, standard ultrasound images were stored. The time spent on transverse ultrasonography for each child was recorded.

2.3. Assessment

The ultrasound images were read by a senior pediatric orthopedist specialized in pediatric musculoskeletal sonography. The analysis of each patient determined whether there was an intact or disrupted cartilage hinge by transverse ultrasonography. If the cartilage hinge was intact, it was thought that the fracture was stable and a long-arm cast should be placed. If the cartilage hinge was disrupted, it could be considered that the fracture was unstable and surgical treatment should be recommended. Pediatric patients usually follow-up for radiographic assessment at 1, 2, and 4 weeks after the injury.

2.4. Statistics

For statistical analysis, we recorded pediatric patients with minimally displaced LHCF who had intact or disrupted cartilage hinges, and we recorded whether the distal fracture fragment was displaced or not after they underwent conservative or surgical treatment. The percentages were calculated for quantitative variables.

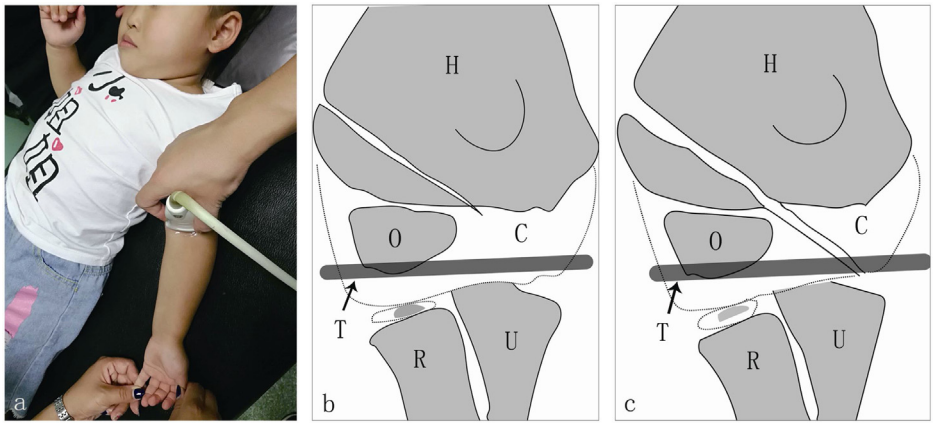

Fig. 1. Patient and transducer position of transverse ultrasonography; a: photograph showing the patient and transducer positioning; b: schematic drawing showing the transducer position of intact cartilage hinge; c: schematic drawing showing the transducer position of disrupted cartilage hinge. H: humerus, O: center of ossification of capitellum epiphysis, C: cartilage of epiphysis, T: transducer, R: radius, U: ulna.

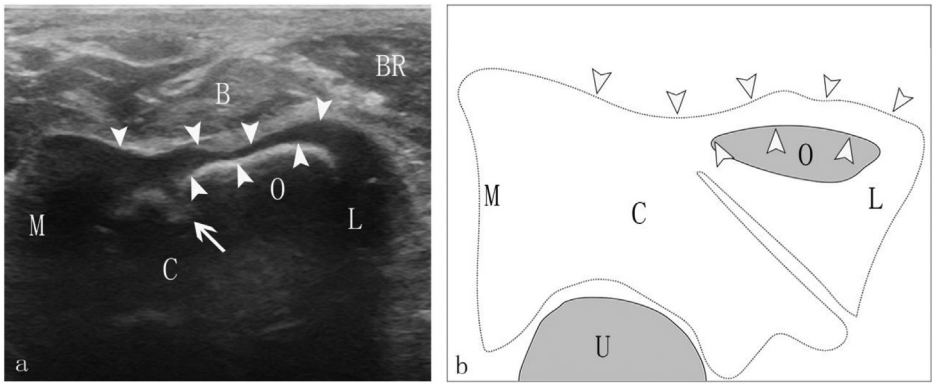

Fig. 2. Transverse ultrasound image and schematic drawing showing the intact cartilage hinge; a: transverse ultrasound image; b: schematic drawing. B: brachialis, BR: brachioradialis, M: medial, L: lateral, O: center of ossification of capitellum epiphysis, C: cartilage of epiphysis, U: ulna, arrowhead: cartilage hinge, arrow: hemorrhage.

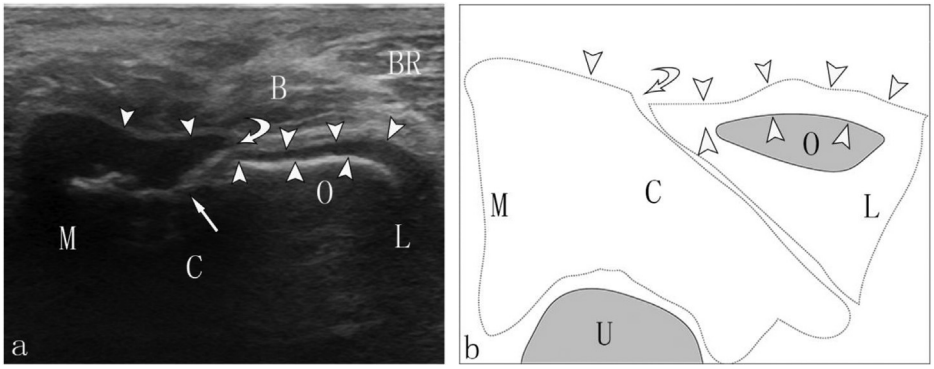

Fig. 3. Transverse ultrasound image and schematic drawing showing the disrupted cartilage hinge; a: transverse ultrasound image; b: schematic drawing. B: brachialis, BR: brachioradialis, M: medial, L: lateral, O: center of ossification of capitellum epiphysis, C: cartilage of epiphysis, U: ulna, arrowhead: cartilage hinge, curved arrow: stair sign of disrupted cartilage hinge, arrow: massive hemorrhage.

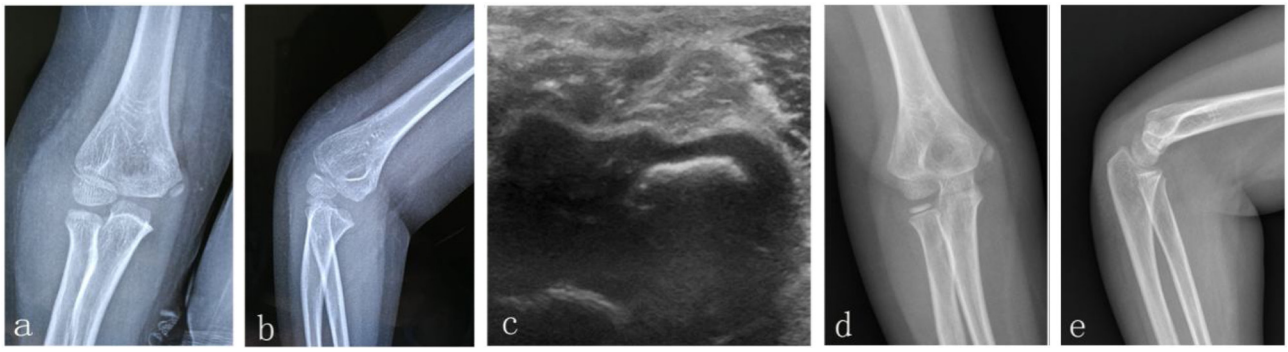

Fig. 4. Patient in case 8; a, b: initial anteroposterior and lateral radiography of minimally displaced lateral humeral condyle fracture with intact cartilage hinge; c: transverse ultrasonography showing intact cartilage hinge; d, e: anteroposterior and lateral radiography showing complete union of the fracture after conservative treatment.

3. Results

The study enrolled 39 children who averaged 4.5 years of age (2–11). There were 24 boys and 15 girls. The ultrasound examination was performed at an average of 15 hours (6–48) after the injury (many patients were transferred from other cities). The transverse ultrasound examination took an average of 4 minutes to determine the integrity of the cartilage hinge. The average examination time for children under 5 years old was 4.7 minutes, and the children over 5 years old was 3.1 minutes. Among the 39 children with minimally displaced LHCF on the radiographs, 14 children had intact cartilage hinges (Fig. 4) with an average age of 4.8 years, and 25 children had disruption of the cartilage hinge with an average age of 4.6 years (Table 1). No children needed sedation or general anesthesia during the ultrasound examination.

Fourteen children with intact cartilage hinges of the minimally LHCF received conservative treatment with a long-arm cast at 90 degrees of flexion and neutral rotation. Among the 25 children with the minimally displaced LHCF, 16 underwent surgical intervention to achieve anatomical reduction of the articular surface with smooth percutaneous pins; the 9 remaining children with disruption of the cartilage hinge were treated conservatively by immobilization in a long-arm cast. Among these 9 cases, further displacement was detected in 5 cases during an average of 12.6 days (7 to 18) after treatment by cast immobilization (Fig. 5). There were no cases of further displacement among the 14 children with intact

Table 1
Patient characteristics and transverse ultrasonography data.

Patient	Age (years)	Time consumed (minutes)	Integrity of cartilage hinge	Treatment	Follow-up
1	4	3	I	CT	CN
2	3	5	D	ST	CN
3	3	4	D	CT	CN
4	2	5	D	ST	CN
5	4	4	I	CT	CN
6	5	3	D	ST	CN
7	5	3	D	CT	FD
8	8	2	I	CT	CN
9	4	5	D	ST	CN
10	6	3	D	CT	FD
11	2	6	I	CT	CN
12	3	4	D	ST	CN
13	6	3	D	CT	CN
14	9	2	D	ST	CN
15	3	4	I	CT	CN
16	4	4	D	CT	FD
17	4	5	D	ST	CN
18	7	3	I	CT	CN
19	4	4	D	ST	CN
20	11	3	I	CT	CN
21	5	4	I	CT	CN
22	9	3	D	ST	CN
23	6	3	D	ST	CN
24	5	4	D	CT	CN
25	2	6	I	CT	CN
26	4	5	I	CT	CN
27	7	3	D	ST	CN
28	3	6	I	CT	CN
29	4	3	D	ST	CN
30	6	3	D	ST	CN
31	5	3	D	CT	FD
32	5	4	D	ST	CN
33	3	6	I	CT	CN
34	3	5	I	CT	CN
35	4	5	D	CT	FD
36	4	4	D	ST	CN
37	6	4	I	CT	CN
38	4	5	D	ST	CN
39	3	6	D	CT	CN

I: intactness; D: disruption; CT: conservative treatment; ST: surgical treatment; CN: complete union; FD: further displacement.

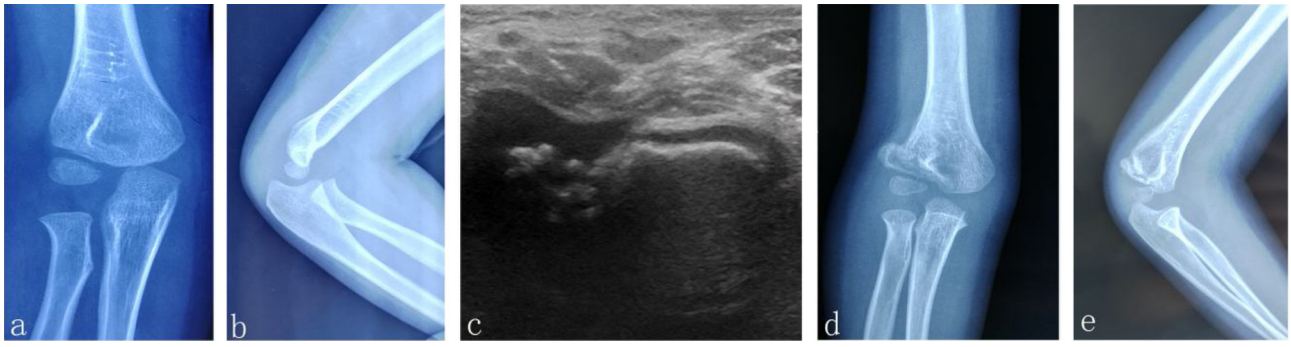

Fig. 5. Patient in case 7; a, b: initial anteroposterior and lateral radiography of minimally displaced lateral humeral condyle fracture with disrupted cartilage hinge; c: transverse ultrasonography showing disruption of the cartilage hinge; d, e: anteroposterior and lateral radiography showing late displacement of the fracture after conservative treatment.

cartilage hinges who were treated conservatively or among the 16 children with disruption of the cartilage hinge treated surgically (Table 2).

4. Discussion

In this study, transverse US was efficient to determine the integrity of the cartilage hinge in minimally displaced LHCF: the working hypothesis is confirmed. We found that 9 of the 25 children with disruption of the cartilage hinge received conservative treatment by cast immobilization, and 5 of them had further displacement, accounting for 56%. Meanwhile, all 14 patients with intact cartilage hinges had no further displacement when treated conservatively. This indicates that if the cartilage hinge is intact, the fracture is stable and can be treated conservatively, and if the cartilage hinge is disrupted, the fracture is unstable and there is a high risk (56%) of further displacement.

We also found that 16 of the 25 children with disruption of the cartilage hinge underwent surgical treatment with percutaneous pins, and in none of them was late displacement detected. This indicates that surgical treatment is an appropriate treatment for children with disruption of the cartilage hinge.

Table 2
Follow-up of minimally displaced lateral humeral condyle fracture after conservative and surgical treatment.

Follow-up	Intactness of cartilage hinge $n = 14$	Disruption of cartilage hinge $> n = 25$	
	Conservative treatment $n = 14$	Conservative treatment $n = 9$	Surgical treatment $n = 15$
Complete union	14	5 (56%)	15
Late displacement	0	4 (44%)	0

Table 3
Comparison of advantages and disadvantages among arthrography, MRI, elbow arthroscopy and ultrasonography.

	General anesthesia or sedation	Radiation	Invasive procedure	Risk of infection	Need an appointment	False negative results	Dynamic investigation	Cost
AG	+	+	+	+	+	+	+	+
MRI	+	–	–	–	+	–	–	+
EA	+	–	+	+	+	–	+	+
US	–	–	–	–	–	–	+	–

AG: arthrography; EA: elbow arthroscopy; US: ultrasonography.

Optimal treatment of minimally displaced LHCF in children is difficult, because it is not clear whether the cartilage hinge is complete. If all of minimally displaced LHCF are immobilized with the long arm cast, some of fractures may undergo secondary displacement during conservative treatment with consequent poor outcomes [9–18]. If all of these fractures are treated with surgery, some children may undergo unnecessary surgery [19,20].

Jakob et al. [4] discovered that the LHCF were sometimes hinged on intact cartilage. Horn et al. [12] showed that no patients with intact cartilage hinge experienced further displacement after conservative treatment. Thevenin-Lemoine et al. [13] reported that two in eight patients had further displacement of the lateral condyle with disruption of the cartilage hinge at 7 and 11 days after the fracture. This suggested that minimally displaced LHCF with an intact cartilage hinge do not displace further and heal with conservative treatment. Nevertheless, there is a risk of further displacement if the cartilage hinge of the fracture is disrupted. The intactness or disruption of the cartilage hinge is the pivotal factor for stability of minimally displaced LHCF.

There are various methods to assess the integrity of the cartilage hinge. Elbow arthrography has been introduced to detect cartilage lesions of lateral condyle fractures to distinguish stable from unstable fractures [21]. However, elbow arthrography is an invasive procedure and requires general anesthesia in children; furthermore, hematoma on the displaced cartilage surface may create false negative results [12]. MRI can clearly detect the extent of the fracture line to distinguish the integrity of cartilage hinge [12–19]. Thevenin-Lemoine et al. [13] recently reported that use of T2-weighted and PD Fat Sat sequences of MRI to analyze the LHCF can reduce the time to accomplish the scout scans. However, MRI examinations also require sedation most of the time. Moreover, it usually requires an appointment at most medical institutions and quick judgments cannot be made [22]. Elbow arthroscopy can directly visualize the lesion of the cartilage hinge and accurately evaluate the stability of lateral condyle fractures [22,23]. However, it also requires general anesthesia, and there is a risk of nerve injury, infection and compartment syndrome [24,25]. Comparison of advantages and disadvantages among arthrography, MRI, elbow arthroscopy and ultrasonography was show in Table 3.

Ultrasonography uses no ionizing radiation, there is no need for general anesthesia, and it is a noninvasive technique that is especially useful in minimally displaced LHCF [16–26]. Davidson et al. [27] reported that the injury of elbow could be evaluated by US, they used sagittal ultrasound images of lateral, middle and medial parts of distal humerus; transverse ultrasound images of anterior and posterior aspects of metaphysis and coronal ultrasound images of lateral and medial aspects of humerus to identify diagnosis and treatment in eight pediatric patients. Vocke-Hell et al. [17] noted that the standard longitudinal and transverse US technique was able to distinguish between stable fractures and unstable fractures in six children. Zhang et al. [15] also demonstrated that the stability of LHCF could be ascertained by the longitudinal and transverse US technique in nine pediatric patients.

In contrast to the previous reports, we utilized a novel transverse US technique to assess the integrity of the cartilage hinge and to evaluate the stability of the fractures. The transducer was located at the distal end of the articular cartilage, the transverse ultrasound image of this area has clear anatomical landmarks. The cartilage hinge whit hypoechoic layer and hyperechoic cortex below the brachialis and brachioradialis, and the two muscles are separated by intermuscular septum. Although this novel technique not provide all the information about the fracture, it can provide enough information to determine the integrity of the cartilage hinge.

In our study, the integrity of the cartilage hinge was accurately documented within only 3 to 6 minutes by transverse ultrasonography; the operation time is shorter and the operation process is simpler than previous reported [15,16]. Previous reports have described that US needs a long learning curve and so much technical experience that it usually requires a trained radiologist to perform the procedure [17–19]. These limitations of US restrict its application for minimally displaced LHCF. This technique effectively reduces the difficulty of the procedure and makes US easier and faster than before.

A limitation of our study is that it is a retrospective study. The transverse US was performed in pediatric patients who had minimally displaced LHCF, and displaced fractures were excluded from the study. This might biased our patients collectively towards the fracture with intact cartilage hinge. However, the management of minimally displaced LHCF is the most controversial, and the management of displaced fractures is reach a consensus [6–8]. Therefore, we do not consider that this compromised our results. In addition, the transverse US technique could be completed readily by a single pediatric orthopedist, and the integrity of the cartilage hinge is easily determined by ultrasound images. Even then, another limitation of our study is that we did not to access intraobserver and interobserver reliability of the results of the technique. Lastly, our study did not include the internal oblique radiographs of minimally displaced LHCF [28]. It is an interesting topic to access the agreement between internal oblique images and ultrasound images of the fractures in further research.

5. Conclusion

The novel transverse US technique can be used to accurately and readily determine stability of minimally displaced LHCF to avoid inadequate treatment and unnecessary surgery. The transverse US is a simple, safe, inexpensive, nonsedating and noninvasive technique. We recommend its routine use in the assessment of minimally displaced LHCF.

Disclosure of interest

The authors declare that they have no competing interest.

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Authors' contribution

Xiong-tao Li: designing the study, collecting and analyzing the data, drafting and revising the manuscript.

Xian-tao Shen: performing the ultrasound examination, collecting and analyzing the data, revising the paper.

Xing Wu: performing the ultrasound examination, collecting and analyzing the data.

Xiao-liang Chen: collecting and analyzing the data.

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