Ultrasonography guided Closed Reduction in the Treatment of Displaced Transphyseal Fracture of the Distal Humerus

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Abstract

Background: To evaluate the clinical and radiographic outcomes after ultrasonography guided Closed reduction in the treatment of displaced transphyseal fracture of the distal Humerus (TFDH).

Methods: Twenty-seven patients with displaced TFDH successfully treated by the ultrasonography guided closed reduction during January 2012 to December 2016 were retrospective reviewed. After mean follow-up of 34.88 months, the clinical and radiographic outcomes of patients were evaluated. The cubitus varus of the affected elbow were also assessed at latest follow-up.

Results: The successful rate of ultrasonography guided closed reduction in the treatment of displaced TFDH was 84% (27/32). The twenty-seven patients with successful reduction were included for the following analysis. There were 20 male patients and 7 female patients included the study and the mean age at treatment was 15.39±3.10 months, seventeen fractures occurred in right side elbow and ten in left side. At the last follow-up, there were significant decreases in the elbow flexion (3°, P=0.027) and range of motion (5°, P=0.003) between the injured and uninjured elbow, respectively. Whereas no difference in elbow extension was detected (P=0.110). Flynn's criteria assessment showed that all the patients achieved excellent or good outcomes both in the functional and cosmetic categories. The clinical and radiographic carrying angle at the last follow-up were 11.67 ± 3.11° and 10.46 ± 3.88°, respectively. And the incidence of cubitus varus after treament was 7.4% at last follow-up.

Conclusion: The ultrasonography guided closed reduction in the treatment of displaced TFDH is an effective procedure, the adequate fracture reduction can be acquired with the advantages of real-time, non-radioactive, and simple utilization. With the percutaneous pining fixation, satisfactory clinical and radiographic outcomes can be achieved with low incidence of postoperative cubitus varus.

Introduction

The transphyseal fracture of distal humerus (TFDH) is a rare and occurring in young children below age of three years old[1]. Owing to the unossification of most epiphyseal centers of elbow at this age, most of the distal humerus epiphysis cannot be visualized directly on radiograph, or only the capitellum ossification center can be seen[2, 3]. Nowadays, as the deep understanding of TFDH, it is sufficient to make diagnosis according to the age and the typical radiographic manifestations that posteromedial displacement of proximal radio-ulnar complex relative to the distal humeral metaphysis[4].

Owing to the low incidence of TFDH, many previous studies just reported case reports on this injury with limited impacts on the treatment of TFDH. Recently, some studies reported retrospective studies with small number of consecutive cases[5, 6]. However, the consensus on the normalized treatment has not been reached, and it is still a need of further seeking on the most appropriate treatment strategy for the TFDH. The open reduction enabled the fracture reduced under the direct vision that can ensure the approximate anatomic reduction. However, there are some inevitable risks involved such as wound
infection, bleeding and local scars\textsuperscript{[7]}. Closed reduction can avoid most complications related to the open incision. As the closed reduction and percutaneous pining fixation has been established as the conventional procedure in treating displaced supracondylar fracture\textsuperscript{[8]}. Closed reduction with percutaneous K-wire fixation has also became a widely acceptable technique in the treatment of the TFDH\textsuperscript{[9]}. The closed reduction were assisted by the X-ray fluoroscopy. Therefore, a great quantity X-ray is commonly unavoidable to achieve accurate reduction and realignment, that will resulting in considerable radiation exposure of both surgical staff and patients. Nevertheless, intraoperative elbow arthrography is necessary when treating TFDH with closed reduction which is an invasive procedure with a risk of infection\textsuperscript{[10]}. US is a non-invasive technique that is well-tolerated by children of all ages. And the high-resolution transducers depict internal musculoskeletal structures well, which are generally sufficient in infants and young children\textsuperscript{[11]}. Some case reports had introduced the utilization of ultrasound in the diagnosis, treatment and assessment of the TFDH\textsuperscript{[12, 13]}. To our best knowledge, there is no research on the consecutive cases about the intraoperative ultrasound (US) guided reduction of TFDH. In this work, we describe a procedure which uses intraoperative US to assist closed reduction of displaced TFDH and further evaluate the clinical and radiographic outcome, retrospectively.

**Methods**

**Patients selection**

After institutional review board approval by Children's Hospital of Chongqing Medical University, we screened patients with the diagnosis of the TFDH from January 2012 to December 2016 to in our single tertiary medical institution. Our inclusion criteria were 1) patients were initially diagnosed with transphyseal fracture of the distal humerus, and we reviewed all the patients' preoperative radiographic data to identify the diagnosis; 2) all the patients should be underwent closed reduction guided by US as first choice. 3) patients and their radiographic data were followed for at least 24 months. The excluded criteria were 1) patients has been diagnosed as TFDH in the database, whereas excluded the diagnosis of TFDH after thoroughly radiographic screen; 2) the duration from injury to treatment was more than five days; 3) patients who did not underwent closed reduction attempt as the first treatment choice. 4) patients who underwent reduction without US guidance. 5) patients with their the follow-up duration less than 24 months. 6) patients with incomplete clinical and radiographic data at presentations. 7) patient's age at the treatment was more than three years old.

**Surgical technique**

The procedure is performed under general anesthesia. After reassurance of the fracture displacement of the affected elbow by C-arm fluoroscopy. The high resolution ultrasonography (SonoSite, 5–10 MHz; Inc., Bothell, WA) was used to guide closed reduction intraoperatively. the transducer was coated with a sterile endoscope cover. And the iodophor was used as ultrasonic couplants. During reduction manipulation, ultrasound imaging of the distal humerus were performed in two standardized longitudinal sectional
planes which were the radial/lateral side and the posterior side. The radial side ultrasonography was used to show the lateral displacement of fracture, meanwhile, the posterior ultrasonography was used to show the posterior displacement of the fracture. The reduction maneuvers are similar to those used for supracondylar fractures. Briefly, all the patients were in the supine position, we first corrected the lateral displacement by pushing the distal fracture fragments under the gentle traction with elbow in extension. The ultrasonic transducer was placed to the radial side of the elbow to assess the reduction of the lateral displacement of the fracture. Next, the elbow is flexed while pushing the olecranon with the thumb to correct the posterior displacement of the distal humeral epiphysis. At the same time, the forearm was pronated or supinated to correct the rotation of the fragment. The ultrasonic transducer was placed to the posterior side of the distal humerus to evaluate the posterior displacement of the distal fracture end (Fig. 1). Once the reduction of fracture has been achieved, the elbow was maintained in the maximum flexion to stabilize the reduction and fixation by two K-wires (1.4 mm – 1.6 mm in diameter) through percutaneous pinning with use of a crossed-pin configuration. And the fracture reduction was further confirmed through radiography that the corrected relationship between the distal humeral and forearm. After assurance the reduction, the pins are then bent and cut, the arm is placed in long arm casting, and the child is awoken from anesthesia. The long-arm casting plaster was utilized to assist the immobilization of the fracture till the removal of the internal fixation pins.

Follow-up
Elbow plain film was taken postoperatively immediately, at 2, 4, 6 weeks after operation, respectively. Surgeon evaluated the fracture healing and decided the removal of the internal fixation pins. Thereafter, patients were followed at the interval of three months till the last follow-up.

Clinical evaluation
The clinical outcomes of patients at the last follow-up were evaluated using Flynn's criteria. The flexion and extension ranges and the carrying angles of the both the affected and unaffected elbow were assessed with use of a goniometer[14]. The carrying angle was defined the angle formed by the long axis of the arm and the long axis of the forearm in the frontal plane which measured with the elbow extended and the forearm and hand in full supination.

Radiographic evaluation
The radiographic outcomes were evaluated in anterio-posterior and lateral radiographs of both the injured and unaffected elbows at the last follow-up among all the patients. The radiographic carrying angle were measured on the anterio-posterior radiographs according to methods reported by Chapleau et al[14].

Cubitus varus
Cubitus varus deformity was determined by the clinical and radiographic carrying angle, comparing the injured side with the unaffected side at the time of the latest follow-up. Cubitus varus deformity was defined as a difference of > 10° in the clinical or radiographic carrying angle, with the injured side value lower than the unaffected side value.
**Statistic analysis**

All variables were analyzed by SPSS 22.0. Statistical software, and continuous data were indicated by X ± SD and Student ANOVA analysis was used for the comparison of continuous variables. Chi-square test and were used for categorical variables. The level of statistical significance was determined at p < 0.05.

**Results**

**Patients demographic data**

After screen, there are thirty-two patients included in present study, among the 32 included patients, there are 27 patients achieved successful closed reduction under the ultrasound guided, and 5 patients did not achieve closed reduction and need for the further open reduction. The successful rate of US guided closed reduction in the TFDH was 84% (27/32). We enrolled the 27 patients into further analysis. There were 20 male patients and 7 female patients. The average age at the treatment was 15.39 ± 3.10 months (range 9.40 to 19.43). The average follow-up interval was 34.88 ± 7.15 months (range 24.47 to 49.50). At last follow-up, the average age was 50.32 ± 7.25 months (range 40.27 to 65.53). The fracture occurred more commonly in the right side (63%, 17 cases) than that in the left side (37%; 10 cases). The demographic information on the included patients is available in Table 1.

| Gender (n)         | N = 27       |
|--------------------|-------------|
| Male               | 20 (74.07%) |
| Female             | 7 (25.93%)  |
| Laterality (n)     |             |
| Left               | 10 (37.04%) |
| Right              | 17 (62.96)  |
| The age of injury (months) | 15.39 ± 3.10 (9.40–19.43) |
| Average time to surgery (day) | 2.04 ± 1.13 (1–4) |
| Follow-up (months) | 34.88 ± 7.15 (24.47–49.50) |
| The age at last followed (months) | 50.32 ± 7.25 (40.27–65.63) |

**Clinical outcomes**

At last follow-up, the average flexion of the injured elbow was a mean of 145.26 ± 4.94°, and the average extension of the injured elbow was 4.57 ± 4.45°. Differences in elbow flexion were detected between the injured and uninjured side (P = 0.027). However, there was no significant difference in elbow extension.
between the injured and uninjured side (P = 0.110). The mean range of motion is significant decrease in injured side when compare to the normal side which was 138.63 ± 5.95° and 143.76 ± 5.95°, respectively (P = 0.003). The mean clinical carrying angle at the last follow-up was 11.67 ± 3.11° for the injured side and 10.63 ± 7.16° for the normal side, no difference was detected (P = 0.493). (Table 2)

| Outcomes                      | Degrees (°)                      | F     | p     |
|-------------------------------|----------------------------------|-------|-------|
| Flexion elbow of the affected | 145.26 ± 4.94 (136.0-157.0)      | 5.154 | 0.027 |
| Flexion elbow of the unaffected| 148.33 ± 5.01 (139.0-161.0)      |       |       |
| Elbow extension of the affected| 6.63 ± 4.83 (-1.5-14.0)          | 2.642 | 0.110 |
| Elbow extension of the unaffected| 4.57 ± 4.45 (-6.5-10.0)         |       |       |
| ROM of the affected            | 138.63 ± 5.95 (127.0-150.0)      | 10.045| 0.003 |
| ROM of the unaffected           | 143.76 ± 5.95 (130.5-155.0)      |       |       |

The clinical outcomes were also classified as excellent, good, fair, or poor according to the Flynn's criteria. There were two factors including the loss of motion and the loss of carrying angle in degrees that compared to the normal elbow. The functional result was excellent in 21 patients (77.78%) and good in 6 (22.22%). The cosmetic result was excellent in 23 patients (85.19%) and good in 4 (14.81%). No patients were noted as the fair or poor grade either in the functional and cosmetic evaluation. (Table 3)
Table 3
Functional and cosmetic outcomes according to Flynn’s criteria. (Affected elbow vs. Unaffected elbow)

| Outcomes                                      | Number                  |   |   |   |   |
|-----------------------------------------------|-------------------------|-----------------------|------------------|-----------------|------------------|-----------------|-----------------|-----------------|
|                                               |                         | Affected elbow        | Unaffected elbow  | χ               |                  |                 |                 |                 |
| Functional, loss of range of motion (degrees) |                         |                       |                   |                 |                  |                 |                 |                 |
| Excellent (0–5)                               | 21 (77.78%)             | 27 (100.00%)          | 0.030             |                 |                  |                 |                 |                 |
| Good (5–10)                                   | 6 (22.22%)              | 0 (0.00%)             |                   |                 |                  |                 |                 |                 |
| Fair (10–15)                                  | 0 (0.00%)               | 0 (0.00%)             |                   |                 |                  |                 |                 |                 |
| Poor (>15)                                    | 0 (0.00%)               | 0 (0.00%)             |                   |                 |                  |                 |                 |                 |
| Cosmetic, difference in carrying angle (degrees) |                         |                       |                   |                 |                  |                 |                 |                 |
| Excellent (0–5)                               | 23 (85.19%)             | 27 (100.00%)          | 0.119             |                 |                  |                 |                 |                 |
| Good (5–10)                                   | 4 (14.81%)              | 0 (0.00%)             |                   |                 |                  |                 |                 |                 |
| Fair (10–15)                                  | 0 (0.00%)               | 0 (0.00%)             |                   |                 |                  |                 |                 |                 |
| Poor (>15)                                    | 0 (0.00%)               | 0 (0.00%)             |                   |                 |                  |                 |                 |                 |

Radiographic outcomes

At last follow-up, the radiographic carrying angles of the both injured elbow and normal elbow was measured. The mean carrying angle was 10.46 ± 3.88° in injured elbow and 10.48 ± 3.03° in the normal side, respectively. There were no significant differences between the injured side and the unaffected side (P = 0.752) (Table 4).

Table 4
The radiographic carrying angles. (Affected elbow vs. Unaffected elbow)

|                                           | Affected elbow (°) | Unaffected elbow (°) | F   | p   |
|-------------------------------------------|--------------------|----------------------|-----|-----|
| Carrying angle of body surface            | 11.37 ± 4.14 (-4.0-19.0) | 10.93 ± 2.93 (2.0–15.0) | 0.027 | 0.651 |
| Carrying angle of radiographs             | 10.46 ± 3.88 (-4.20-18.10) | 10.48 ± 3.03 (3.20–14.70) | 0.020 | 0.889 |

Cubitus varus

Two patients (2/27, 7.4%) showed a cubitus varus deformity according to our criteria that aforementioned. The two patients demonstrated the deformity on both radiographs and clinical examination.
Discussion

Ultrasonography is a noninvasive and rapidly available technique which is well applied in the diagnosis of musculoskeletal injury in infants and young children\textsuperscript{[15]}. Supakul et al.\textsuperscript{[16]} suggested that although the posteromedial displacement of the proximal forearm on the radiography is highly suggestive of TFDH, the definite diagnosis can be confirmed with ultrasound. Dias et al.\textsuperscript{[17]} firstly described the ultrasonic diagnosis of TFDH. They demonstrated that the ultrasonography image characteristics of the distal humerus that the cartilaginous epiphysis is depicted as a hypoechoic structure with sparkling echoes within it, whereas the cortical bone appears as a highly echogenic structure with posterior acoustic shadowing. In addition, the sonography is a noninvasive examination without ionising radiations which could obviates elbow arthrography in the detection of TFDH. More important, it can also show the direction and extent of fracture displacement which is essential for the guidance of reduction manipulation\textsuperscript{[18]}. 

Previous study has reported the US could detect cortical discontinuities of 1 millimeter or more\textsuperscript{[19]}. Some recent literature also introduced the utilization of ultrasound guided reduction in forearm and femoral fractures\textsuperscript{[20–22]}. In particular, ultrasonography has the special ability to display the image of the cartilages at the distal part of the humerus in children. Furthermore, intraoperative US guided reduction provides the image of the fracture displacement continuously in real-time, which help surgeons manipulating the distal segment to reduce without radiation exposure. In present study, all the fracture reductions were performed under US guidance initially. We achieved a satisfactory successful rate of closed reduction which was 84\% (27/32). Some researchers doubted that ultrasound may have limited use because of the requirement of significant expertise in performing and interpreting the examination\textsuperscript{[23, 24]}. In fact, we simplified the complicated procedures of ultrasonography that adopted in the diagnostic examination which need to multi-planes scanning\textsuperscript{[15]}. As the preoperative imaging examination has been shown the displacement of the fracture comprehensively. As a result, the aim of intraoperative sonography is offering the images to assure the reduction of fracture displacement in the lateral and posteroanterior planes. In present study, the ultrasonography in the lateral and posterior plane could adequately and effectively show the structures at fracture site and guide intraoperative reduction.

The cubitus varus deformity that seems to be the most common complication after TFDH. Nevertheless, the definite reason of the cubitus varus has not been elucidated. Previous studies reported a variable incidence of cubitus varus after treatment of TFDH which were ranged from 25 to 70\%\textsuperscript{[25]}. In present series, the incidence of cubitus varus after closed reduction was 7.4\%, which is comparable to Hariharan et al’s recent multicenter review\textsuperscript{[24]}. The lower incidence of the cubitus varus in present study might be attributed to the following reasons. It has been reported that a higher frequency of varus deformity in children less than two years of age in the previous studies\textsuperscript{[26]}. However, most patients in present study were relative elder toddlers with the average age of 15 months which were different than mostly studies included neonates. Secondly, owing to the less remodeling potential of the distal humerus, the cubitus varus seem to be not progressive\textsuperscript{[27]}. an the inadequate reduction could be the main cause of cubitus
varus in toddlers with TFDH\textsuperscript{6}. In present study, all the reduction was guided by the US, and nearly anatomy reduction could be guaranteed in most cases which thus avoiding the cubitus varus effectively. Thirdly, it has been reported that stable fixation after reduction is also an important factor in preventing cubitus varus\textsuperscript{[24, 28]}. In present study, considering the maintenance of displaced fracture reduction may be difficult, especially if elbow swelling was presented and then decreased, the plaster immobilization alone could not be maintained the reduction stably. All the patients were underwent reduction following percutaneous pinning fixation. In agreement with previous studies, we think that this stable fixation procedure was contribute to maintain the position after reduction and further accelerate the callus forming at the fracture site.

There are some limitations in present study, this is a retrospective study and the follow-up is relative short, thus the long-term follow-up of clinical and radiographic outcomes are required to evaluate the development of the cubitus varus. The US could guide the fracture reduction intraoperatively, however, the fixation K-wires were penetrated into the bone which were uneasily delineated by ultrasound. Therefore, the radiography is still need to confirm the configuration of the fixation pins intraoperatively.

In conclusion, our study shows the satisfactory clinical and radiographic outcomes in toddlers with displaced TFDH treated by the ultrasound guided closed reduction with percutaneous pining fixation. With the guidance of intraoperative ultrasonography, the adequate fracture reduction can be acquired with the advantages of real-time, non-radioactive, and simple utilization.

**Declarations**

**Ethics approval and consent to participate**

The study was institutional review board approval by Children's Hospital of Chongqing Medical University (No.2020196).

**Consent for publication:**

Not applicable

**Competing interests:**

The authors declare that they have no competing interests.

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**Authors' contributions:**
YZ, HZ, ML and GZ were involved in the conception and design of the project. All authors participated in the surgery implementation. YZ and GZ collected and extracted the data. HZ, YZ and GZ conducted the analysis and data interpretation. HZ and YZ drafted the manuscript. YZ, HZ and ML made the critical revisions. All authors read, provided feedback and approved the final manuscript.

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