JOURNAL OF CHILDREN'S ORTHOPAEDICS

Functional outcome of the elbow in toddlers with transphyseal fracture of the distal humerus treated surgically

W. Zhou[1]
F. Canavese[2]
L. Zhang[1]
L. Li[1]

Level of evidence: Level IV – Therapeutic study

Cite this article: Zhou W, Canavese F, Zhang L, Li L. Functional outcome of the elbow in toddlers with transphyseal fracture of the distal humerus treated surgically. *J Child Orthop* 2019;13:47-56. DOI: 10.1302/1863-2548.13.180156

Keywords: transphyseal fracture of the distal humerus; Delee's classification; cubitus varus; Mayo Elbow Performance Score; functional outcome; reduction

Abstract

Purpose To quantitatively evaluate the upper extremity and elbow function with the Mayo Elbow Performance Score (MEPS) in children with transphyseal fracture of the distal humerus (TFDH) treated surgically.

Methods During the period between 2005 and 2015, a total of 16 patients (ten male, six female) met the inclusion criteria. Mean age at the time of injury was 18 months (11 to 37) and mean follow-up was 42.3 months (6 to 98). Based on a modified version of Delee's classification (Group A to C), the clinical and radiographic outcome of TFDH in toddlers treated surgically were retrospectively evaluated.

Results Mean humeral-ulnar (HU) angle of the injured and non-injured side was 1.2° (-18° to 14°) and 8.8° (2° to 19°), respectively ($p = 0.001$). Closed and open reduction showed similar HU angle values ($p = 0.682$). Mean MEPS score of the injured and non-injured side was 85.5 points (70 to 95) and 95 points (90 to 100), respectively ($p = 0.002$). No significant association was identified between MEPS score and gender, side, age at trauma, direction of displacement, time from trauma to surgery, presence of ossified capitellum, type of surgery and type of fracture.

Conclusion Functional outcome was generally good regardless of surgical procedure performed, closed or open and type of fracture according to modified Delee's classification. However, a residual cubitus varus was commonly observed among toddlers with transphyseal fractures of the distal humerus.

[1]Department of Pediatric Orthopaedics, Shengjing Hospital of China Medical University, Shenyang City, Liaoning Province, China
[2]Department of Pediatric Surgery, University Hospital Estaing, Clermont Ferrand, France

Correspondence should be sent to LI Lianyong, MD PhD, Department of Pediatric Orthopaedics, Shengjing Hospital of China Medical University, No.36 Sanhao Street, Heping District, 110004 Shenyang City, Liaoning Province, China.
E-mail: loyo_ldy@163.com

Introduction

Transphyseal fracture of the distal humerus (TFDH), also known as fracture-separation of the distal humeral epiphysis or epiphysiolysis of the distal humerus, is an uncommon injury that is most frequently seen in children younger than three years of age.[1] Overall, it is the least common of all physeal injuries of the distal humerus.[2] As such, this fracture can be easily misdiagnosed as one of the more common paediatric elbow injuries that usually occur in older children, such as dislocation, lateral condyle or supracondylar fracture.[3,4]

Although the radiographic and clinical outcome and the pathogenetic mechanism of TFDH have been investigated by several authors,[5-10] none of the published studies, mostly small case series without a control group, have evaluated the functional outcome in toddlers treated surgically.[11-15]

The Mayo Elbow Performance Score (MEPS) was developed by Morrey and Adam in 1992.[16-18] Moreover, it also has been shown that MEPS can be used to measure the functional outcome of the elbow and upper extremity in children.[16,17] The MEPS evaluates pain, arc of movement, stability and daily function, and it provides a score ranging from 0 to 100, with a higher score indicating better outcome or function.[18]

The main objective of this study is to retrospectively evaluate the clinical and radiographic outcome of displaced TFDH in toddlers treated surgically and to evaluate upper extremity and elbow function with the MEPS.

Patients and methods

This study was approved by our institutional review board. Medical records were reviewed to identify all patients who

Table 1 Patients' demographics

Case	Gender	Side	Age (mths)	Follow-up (mths)	Displacement	Treatment	SH classification	Modified Delee classification	MEPS	HU angle	Ossified capitellum	Maximum flexion	Maximum extension	Time from trauma to surgery (days)
1	F	L	13	22	PL	CRPP	II	C	NA	0°	Yes	120°	2°	1.2
2	F	L	26	34	PM	CRPP	II	B	85	-3°	Yes	126°	6°	2.3
3	M	R	11	6	PM	CRPP	II	C	NA	-3°	Yes	132°	5°	1.1
4	M	L	30	11	PM	ORPP	I	A	NA	9°	No	74°	-10°	10
5	M	L	15	30	PM	CRPP	II	A	NA	-3°	No	125°	6°	1.7
6	M	R	21	82	PM	ORPP	II	A	85	-18°	No	128°	4°	2.2
7	M	R	13	47	PM	CRPP	II	C	70	-3°	Yes	127°	6°	1.2
8	M	L	13	43	PM	CRPP	I	A	90	11°	No	130°	9°	2.3
9	M	L	14	52	PM	CRPP	I	A	90	-4°	No	130°	-2°	3
10*	F	R	18	24	PM	CRPP	II	C	NA	0°	Yes	128°	4°	3.3
11	M	L	16	39	PM	CRPP	II	C	85	-4°	Yes	125°	5°	0.2
12	F	L	15	98	PL	ORPP	II	C	85	14°	Yes	123°	22°	1.1
13	M	R	37	6	PM	CRPP	II	C	NA	10°	Yes	129°	6°	1.3
14	F	R	12	69	PM	ORPP	II	A	85	-1°	No	129°	10°	1.6
15	M	L	22	38	PM	CRPP	II	B	85	3°	Yes	129°	16°	1.2
16	F	R	12	75	PM	ORPP	II	B	95	11°	Yes	135°	5°	13

*arthrogram
F, female; M, male; L, left; R, right; PL, posterolateral displacement; PM, posteromedial displacement; CRPP, closed reduction and percutaneous pinning; ORPP, open reduction and percutaneous pinning; SH, Salter-Harris classification; MEPS, Mayo Elbow Performance Score; HU angle, humero-ulnar angle; NA, not available

underwent surgical treatment for displaced TFDH in a single centre from January 2005 to February 2015 (Table 1). In total, 22 consecutive patients with displaced TFDH were recorded, of which 18 were surgically treated. Among surgically treated patients, one patient with bilateral TFDH and another with contralateral lateral condyle fracture occurring prior to MEPS evaluation were excluded from the analysis. Finally, 16 surgically treated patients (ten male and six female; 16 elbows) could be included in the present study.

All patients were admitted through the Emergency Department, and the following demographic and clinical data were recorded: gender, age at the time of trauma, side involved, mechanism of injury, presence or absence of associated neurovascular injury and whether the fracture was closed or open.

All the included patients had available anteroposterior (AP) and lateral (L) radiograph of the elbow, MRI was performed to confirm the diagnosis of TFDH in doubtful cases (Fig. 1). Additional information such as time from trauma to surgery, type of surgery (open or closed) and length of postoperative immobilization was collected from the charts.

All fractures were treated under general anaesthesia. Fracture reduction was initially performed by traction and closed manipulations. If successful, percutaneous pinning was performed. One patient underwent elbow joint arthrogram (contrast agent: Iopromide, 1 ml) to confirm the reduction prior to percutaneous pinning. On the other hand, fractures with unsatisfactory reduction and fractures were not possible to reduce with closed manipulations, open reduction and fixation with Kirschner (K)-wires was carried out. After surgery, all patients were immobilized in a long-arm cast for an average period of five weeks (4 to 7) (Fig. 2).

Radiographic evaluation

Fractures were classified according to a modified version of the Delee's classification.[19] According to the modified version of the Delee's classification, fractures were divided into three groups. Group A included TFDH with absent secondary ossification centre of the capitellum, with or without metaphyseal spike; Group B included TFDH with ossified secondary ossification centre of the capitellum, with metaphyseal spike smaller than the ossification centre; Group C included TFDH with ossified secondary ossification centre of the capitellum, with metaphyseal spike bigger than the ossification centre (Fig. 3).

Using AP and L radiographs, the displacement of the distal fragment relative to the axis of the humeral shaft was recorded as anterior or posterior, and medial or lateral.

At last follow-up visit, all patients underwent full AP and L radiographs of the injured and of the non-injured

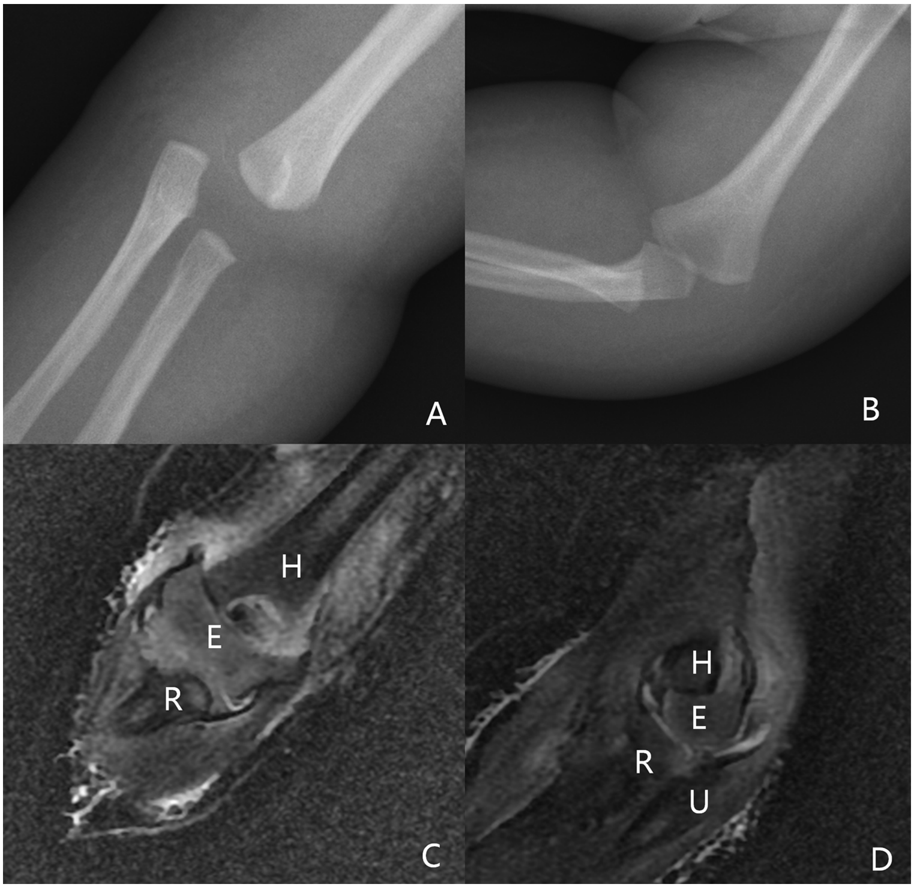

Fig. 1 Five-month-old boy with transphyseal fracture of the distal humerus (modified Delee's classification Group A). Anteroposterior and lateral elbow radiographs (**a** and **b**) and coronal (**c**) and sagittal (**d**) MRI views of the injured elbow (H, humeral distal metaphysis; E, humeral distal epiphysis; R, radius proximal metaphysis; U, ulnar proximal metaphysis).

humerus; humeral length (AP view), humeral-ulnar (HU) angle (AP view; angle between the axis of the humerus and the axis of the ulna) and shaft-condylar angle (L view; angle between the axis of the humerus and the axis of the capitellum) were measured bilaterally in all patients (Fig. 4).

All of the measurements were performed by a single operator (WZ) with a Picture Archiving and Communication System (Neusoft, Shenyang, China).

Functional evaluation

Patients with at least two years of follow-up and aged four years or older (ten out of 16 patients) were asked to complete the MEPS in the outpatient clinic. MEPS is a scale consisting of four domains, corresponding to different symptoms experienced by the patient (pain: 45 points; daily function: 25 points) and clinical signs measured by the examiner (arc of movement: 20 points; stability: 10 points). The overall MEPS score ranges from 0 (most severe functional compromise) to 100 points (normal function).[18] Elbow function can be defined as excellent, if the final score is 90 and more; as good, if score ranges between 75 and 89; fair, if score is between 60 and 74; and poor, if score is lower than 60 (Table 2).[18]

Moreover, at last follow-up visit, all patients underwent bilateral evaluation of passive elbow flexion-extension, as such measurement could be performed in all children, regardless of the age. Maximum elbow joint extension and flexion angle were measured by a single operator (WZ) with a joint goniometer and the resulting arc of movement was expressed in degrees. Full elbow joint extension was considered as 0° with negative values indicating hyperextension.

Follow-up

All patients underwent regular clinical and radiological follow-up for at least six months after index surgery (mean follow-up: 42.3 months (6 to 98)). At each follow-up visit, AP and L radiographs of the affected elbow were taken to assess fracture consolidation and to detect complications such as secondary displacement, re-fracture, hardware migration, infection, nonunion or malunion.

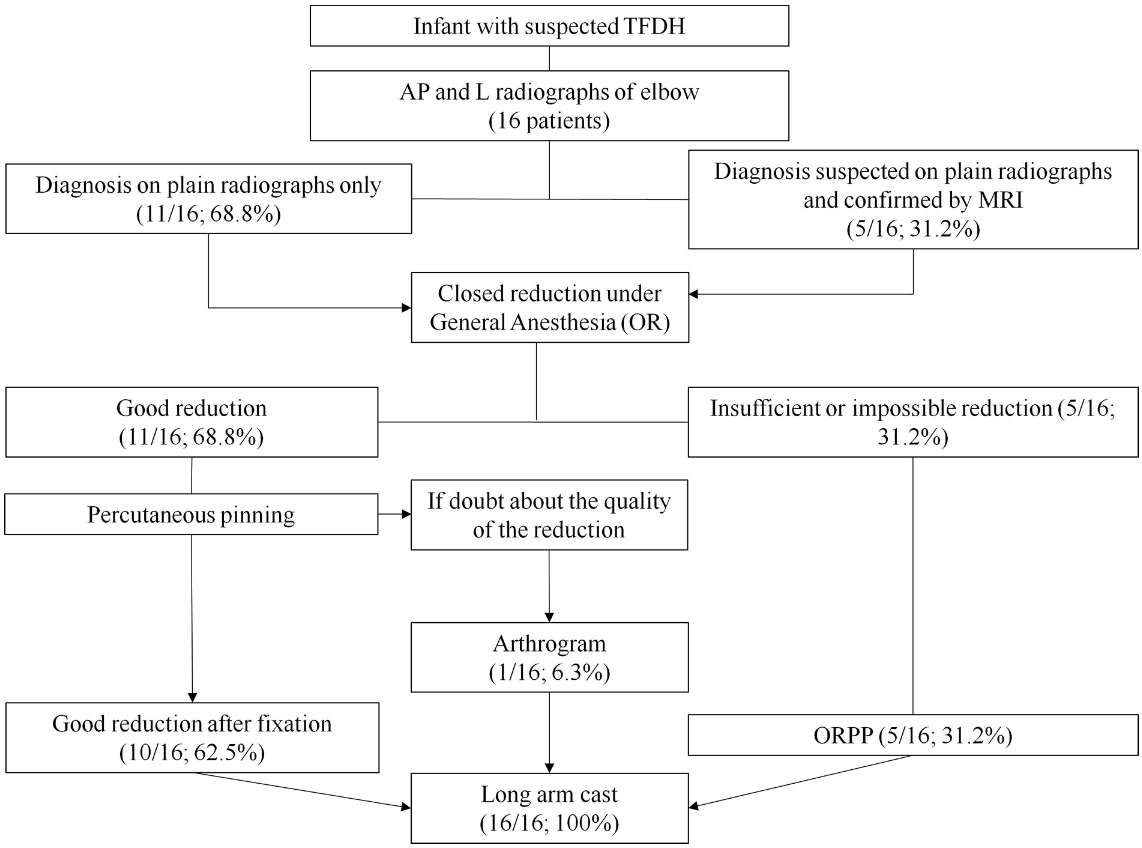

Fig. 2 Diagnostic algorithm (TFDH, transphyseal fracture of the distal humerus; A, anteroposterior; L, lateral; OR, operating room; ORPP, open reduction and percutaneous pinning).

Statistical analysis

This was performed using Statistical Package for the Social Sciences software, Version 17 (IBM Corp., New York, New York). According to treatment method, closed *versus* open reduction, patients were divided into two groups and independent sample *t*-test, paired-sample *t*-test and chi-squared test were used to compare MEPS score, flexion-extension of the elbow, humeral length, HU angle and shaft-condylar angle of the injured and the non-injured side. One-way analysis of variance was used to assess the clinical and radiographic outcome and MEPS functional score in each group of patients (A, B and C) according to the modified version of the Delee's classification.[19] Due to the existence of significant outliers in a small population on the aspects of HU angle (patient 6) and range of movement measurements (patient 4), comparison with and without the outliers was made (Tables 3 and 4). The threshold for significance was set at $p < 0.05$.

Results

The study included a total of 16 consecutive patients with displaced TFDH (ten male (62.5%) and six female (37.5%)) (Table 1). Mean age at the time of injury was 18 months (11 to 37). Side involved was the right in seven cases (43.7%) and the left in nine (56.3%). Mechanism of injury was direct in all cases (fall from a height). Child abuse was ruled out in all patients.

According to the modified Delee's classification,[19] six fractures were in Group A (37.5%), three in Group B (18.8%) and seven in Group C (43.8%); initial fracture displacement was posteromedial in 14 cases (87.5%) and posterolateral in two cases (12.5%).

Patients were treated within 69.9 mean hours from time of trauma (5 to 312). In all, 11 out of 16 patients (68.7%) underwent closed reduction and percutaneous pinning while the remaining five needed open reduction and fixation (31.3%).

Radiographic evaluation

At the time of trauma, the secondary ossification centre of the capitellum was present in ten humerus (62.5%) and absent in the remaining six (37.5%).

At last follow-up visit, the mean humeral shaft-condylar angle of the injured and non-injured side was 47.1° (25° to 59°) and 51.9° (35° to 65°), respectively (p = 0.073),

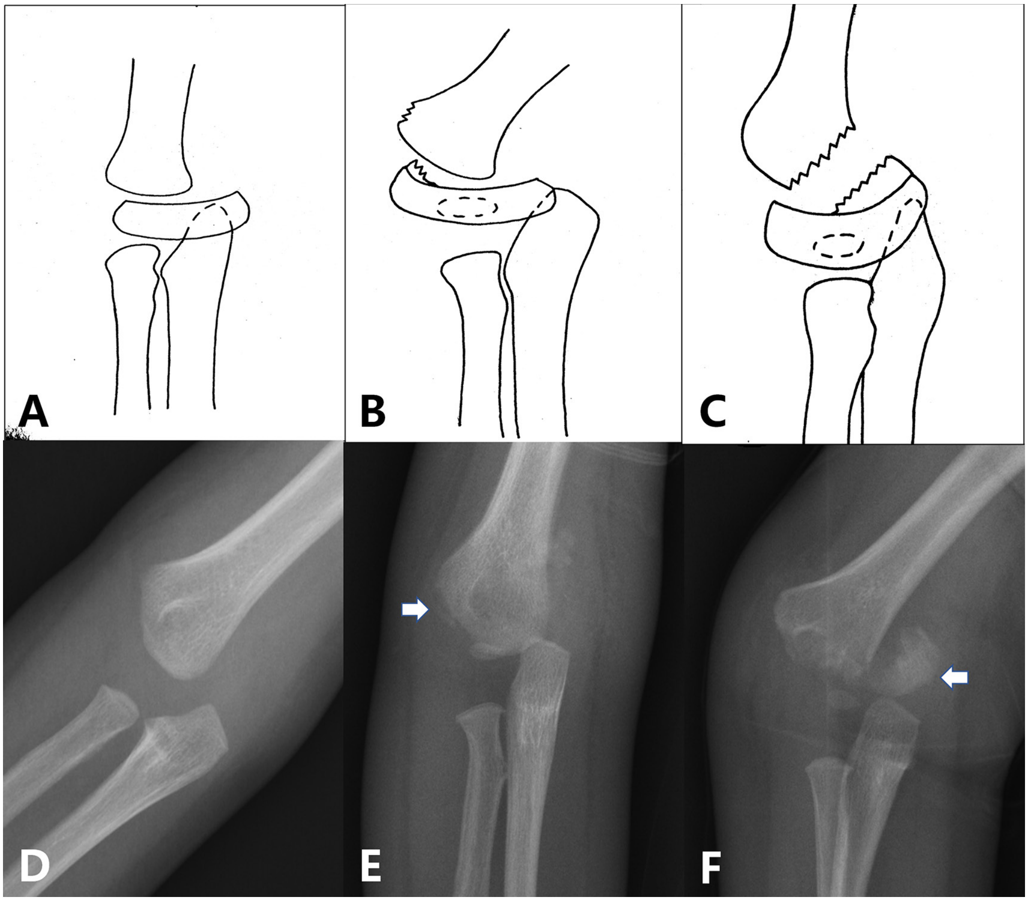

Fig. 3 The modified version of the Delee's classification. Group A: transphyseal fracture of the distal humerus (TFDH) with absent secondary ossification centre of the capitellum, with or without metaphyseal spike (**a** and **d**). Group B: TFDH with ossified secondary ossification centre of the capitellum, with metaphyseal spike smaller than the ossification centre (**b** and **e**). Group C: TFDH with ossified secondary ossification centre of the capitellum, with metaphyseal spike bigger than the ossification centre (**c** and **f**) (arrow = metaphyseal fracture spike).

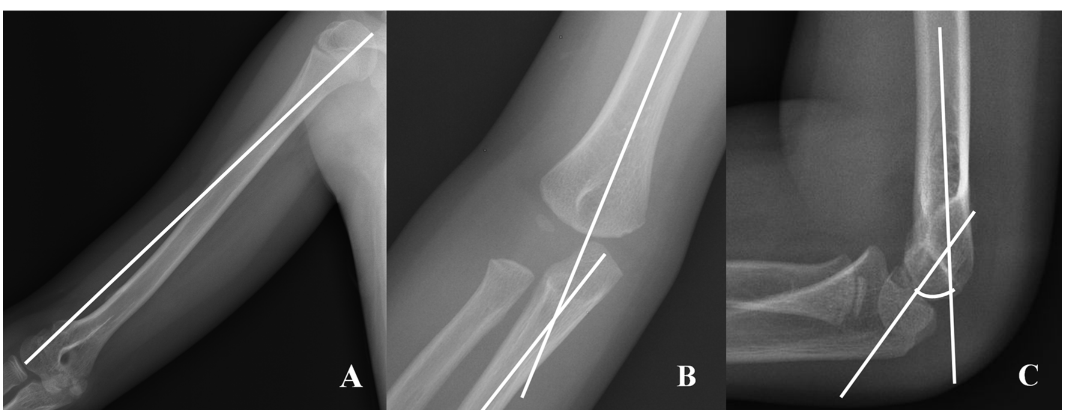

Fig. 4 Radiographic measurement of humeral length (**a**), humeral-ulnar angle (**b**) and shaft-condylar angle (**c**).

independent of type of fracture (p = 0.773); or surgical treatment (closed *versus* open, p = 0.340); the mean HU angle of the injured side was 1.2° (-18°-14°) on the injured elbow, and 8.8° (2° to 19°) on the non-injured side (p = 0.001), independently of type of fracture (p = 0.707); or surgical treatment (closed *versus* open, p = 0.682). Although the mean humeral length was significantly different between injured and non-injured side, 20.3 cm

(15.5 to 25.8) and 20.7 cm (16 to 26.3) ($p < 0.001$), respectively, no clinically significant difference could be identified (Tables 3 and 4).

Functional evaluation

The mean follow-up was 42.3 months (6 to 98). All patients were pain free at last follow-up. Maximum elbow joint extension and flexion angle were assessed in all 16 patients. The mean maximum elbow joint extension angle of the injured and non-injured side was 5.9° (-10° to 22°) and 7.5° (3° to 15°), respectively (p = 0.332). The mean maximum elbow joint flexion angle of the injured and non-injured side was 124.4° (74° to 135°) and 133.1° (123° to 135°), respectively (p = 0.012) (Tables 3 and 4).

Table 2 Mayo Elbow Performance Score between 90 and 100 points is excellent outcome; 75 to 89 is good; 60 to 74 is fair and < 60 is poor outcome

Function	Maximum points	Definition (points)
Pain	45	None (45) Mild (30) Moderate (15) Severe (0)
Motion	20	Arc > 100° (20) 100° > Arc > 50° (15) Arc < 50° (5)
Stability*	10	Stable (10) Moderate instability (5) Gross instability (0)
Daily function	25	Can comb hair (5) Can eat (5) Can perform personal hygiene (5) Can wear a shirt (5) Can wear shoes (5) If unable (0)
Total (maximum)	100	

*Stable means no apparent varus-valgus laxity clinically. Moderate instability means < 10° of varus-valgus laxity. Gross instability means 10° or more of varus-valgus laxity

Maximum elbow flexion (p = 0.311) and elbow extension (p = 0.398) were similar in all patients, irrespective of the type of fracture as per modified Delee's classification.[19]

MEPS score was assessed in patients four years or older at the time of last follow-up visit (ten patients; 62.5%). The mean age of patients whose elbow function was assessed at follow-up was 5.8 years (4 to 9). The mean MEPS score of the injured and non-injured side was 85.5 (70 to 95) and 95 points (90 to 100), respectively (p = 0.002) (Tables 3 and 4).

No significant association between MEPS score and gender (p = 0.246), side (left *versus* right, p = 0.702), age at trauma (p = 0.137), direction of displacement (posteromedial *versus* posterolateral, p = 0.702), type of fracture (p = 0.220), time from trauma to surgery (p = 0.942), presence of ossified capitellum (p = 0.540) and type of surgery (p = 0.552) could be identified.

All patients except one with limited flexion of the elbow (74°), were able to fully participate in daily life and sport activities without discomfort or residual pain.

Discussion

Transphyseal fractures of the distal humerus are rare injuries, and there are few studies focusing on the treatment of these fractures. To the best of our knowledge, the functional outcome of surgical treatment of TFDH in toddlers has never been investigated with a reproducible grading scale.

This study reviewed 16 toddlers with TFDH. All fractures healed, but injured side had significantly lower MEPS score, elbow flexion and HU angle compared with non-injured side (Table 3).

Delee's classification divides TFDH into three groups according to the age of the child and the size (absent,

Table 3 Outcome measurements (injured *versus* non-injured side)

	Maximum flexion	Maximum extension	MEPS*	HU angle	HSC angle	H length (cm)
Injured side	124.4° SD 13.9°	5.9° SD 7.0°	85.5 SD 7.0	1.2° SD 8.2°	47.1° SD 8.4°	20.7 SD 3.0
Non-injured side	133.1° SD 6.0°	7.5° SD 3.4°	95.0 SD 2.6	8.8° SD 4.3°	51.9° SD 9.9°	20.3 SD 3.1
T value	-2.9	-1.0	-4.1	-4.3	-1.9	5.8
p-value	0.012	0.332	0.002	0.001	0.073	< 0.001

*Mayo Elbow Performance Score (MEPS) score was assessed in ten patients out of 16
HU angle, humeral-ulnar angle; HSC angle, humeral shaft-condylar angle; H length, humeral length

Table 4 Outcome measurements after exclusion of 'outlier' patients (injured *versus* non-injured side)

	Maximum flexion*	Maximum extension*	MEPS*	HU angle†
Injured side	127.7° SD 3.7°	6.9° SD 5.7°	86.7° SD 5.9°	2.5° SD 6.6°
Non-injured side	133.7° SD 5.8°	7.6° SD 3.4°	95.3° SD 2.3°	9.1° SD 4.1°
T value	-4.8	-0.5	-5.5	-4.1
p-value	0.001	0.621	0.001	0.001

*comparison after ruling out the outlier patient (number 4, with maximum flexion of 74°)
†comparison after ruling out the outlier patient (number 6, with HU angle of -18°)
MEPS, Mayo Elbow Performance Score; HU angle, humeral-ulnar angle

small, large) of a metaphyseal spike.[19] In particular, Delee reported that Group A fractures tend to occur in patients less than nine months of age; Group B in patients seven to 36 months of age and Group C in patients between three and seven years of age.[19] However, Delee, in his original work, did not provide a precise definition of small and large size spike.[19] Additionally, Oh et al[20] in their review of 12 patients with TFDH could not identify any association between the presence of metaphyseal spike and age. Moreover, Delee's classification does not include patients older than seven years and there is a two month age overlap between Group A and Group B.[14,19] As such, we proposed a modification of the original Delee classification, based on the presence or absence of the secondary ossification centre of the capitellum and on the size of the metaphyseal spike compared with the capitellum (smaller or bigger). We found that type of fracture as per modified Delee's classification does not significantly affect the clinical outcome, and that age at time of trauma is not correlated to the type of fracture ($p = 0.889$), as previously reported by Oh et al.[19,20]

Several studies have shown cubitus varus is the main complication of such injuries during the follow-up period.[15,21,22] Delee et al[19] reported that 25% of patients developed 5° to 10° cubitus varus which did not progress or remodel during follow-up,[19] as also shown by Holda et al.[23] Similarly, McIntyre et al[14] and de Jager and Hoffman[11] found a 30% rate of cubitus varus in their review of 12 and nine patients, respectively. On the other hand, Supakul et al[15] and Tudisco et al[24] found significantly lower rate of cubitus varus deformity, 12.5% and 20% respectively. In Abe et al[12] progressive cubitus varus was found in one out of 21 patients and ascribed to the growth plate injury. Interestingly, the 38-year follow-up study by Tudisco et al[24] revealed 80% of carrying angle variation during follow-up and thought the variation was secondary to the growth plate injury that occurred at the time of trauma. In contrast, Oh et al[20] believe that the deformity is secondary to the avascular necrosis of the medial humeral condyle, as previously reported by Yoo et al[22] in 1992.

When evaluating cubitus varus deformity, both rotation and/or flexion can influence the measurement of HU angle. In order to decrease systemic errors, all the measurements were performed by a single operator. Furthermore, we followed the standard positioning requirements for anteroposterior view of each elbow, including for patients with limited flexion.

In our series, cubitus varus occurred in 50% of patients. In particular, seven out of 16 patients had mild varus and only one patient developed severe cubitus varus deformity. Several authors suggested that avascular necrosis of the medial humeral condyle may be the cause of the deformity,[20,22] but all our patients underwent reduction, either closed or open, and K-wire fixation of the fracture, and none of them developed avascular necrosis of the medial humeral condyle. Other authors claimed that growth plate injury may also be involved in the deformity, as previous studies reported progressive cubitus varus deformity in toddlers with TFDH.[12,24] None of our patients developed progressive cubitus varus deformity during follow-up. Distal humerus growth plate provides 20% of the growth of the bone and 10% of the growth of the entire upper extremity; moreover, by age six to seven years, there is less than 20% of growth remaining at the level of the distal humerus.[25] These growth rates may help to explain why TFDH has low remodelling potential and at the same time it may explain why these injuries tend not to significantly worsen during growth. Therefore, we hypothesized that inadequate or insufficient reduction could be the main cause of cubitus varus in toddlers with TFDH, if avascular necrosis of the medial condyle does not occur. Many authors agreed on this point.[4,11,13,14,26,27] Therefore, anatomical reduction should always be achieved as from an anatomical point of view, when compared with supracondylar fractures, the area of fracture contact is greater, medial tilt is less important and rotation of the distal part of the humerus is less.[19]

Ten out of 16 patients older than four years of age and with more than two years follow-up underwent functional evaluation of the injured elbow and completed the MEPS evaluation. MEPS is a validated functional assessment tool that is widely used for evaluation of clinical outcomes for a variety of elbow disorders, including children.[16-18] Furthermore, it has been shown that MEPS score is a reliable instrument for clinical evaluation of elbow function and is comparable with the American Shoulder and Elbow Surgeons score in an adult population.[28] In our series, functional outcome was excellent in three patients, good in six patients and fair in one patient (Table 1). No significant association between MEPS functional score, type of reduction (closed *versus* open) and type of fracture could be identified. During follow-up, function and cosmetic appearance of the injured elbow were comparable with those of the non-injured side (Table 3) (Fig. 5).

Plain radiographs play an important role in diagnosing the injury. In presence of TFDH there is a loss of the normal alignment between humerus and proximal radius and ulna, on both frontal and sagittal plane. On the frontal plane, the displacement of the proximal radius and ulna can be medial or lateral; it is anterior or posterior on the sagittal plane. On the other hand, in patients with neglected TFDH, the presence of callus, combined with the initial radiographs, contributes to make the diagnosis. Moreover, the presence of an ossified capitellum is a valid aid as the anatomic relationship between proximal radius and capitellum does not change in presence of TFDH, whereas it is modified in cases of elbow dislocation or lateral condylar fracture. In our series, TFDH could be

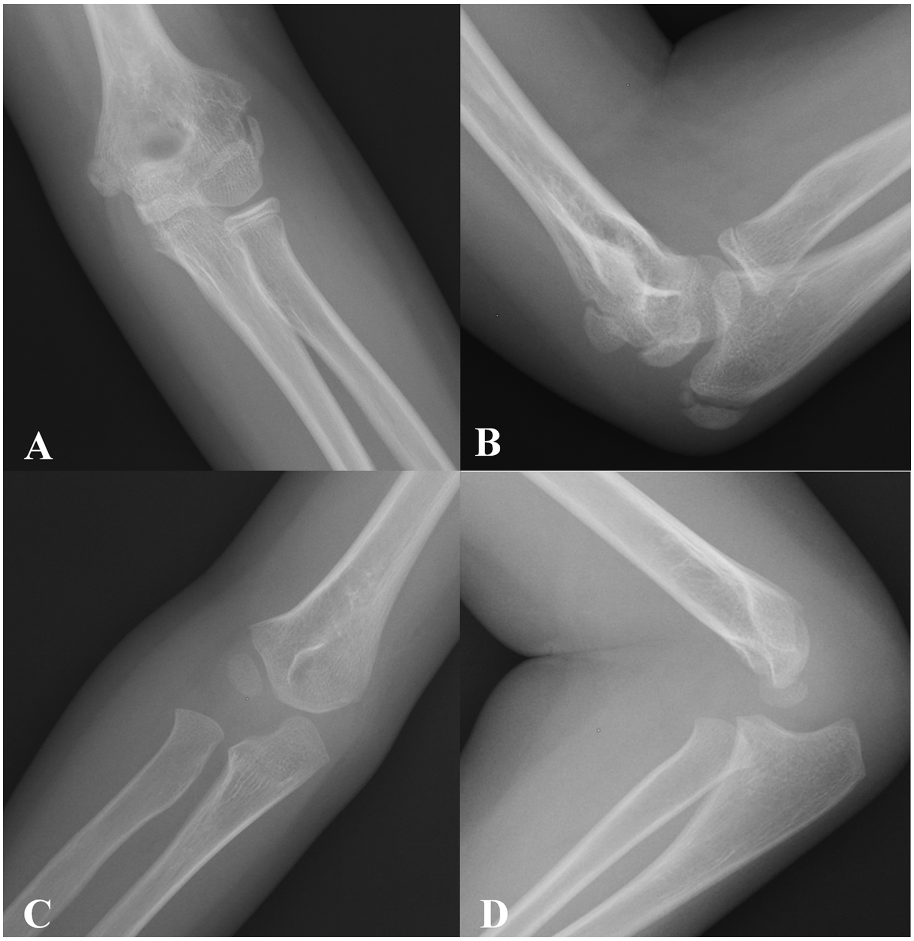

Fig. 5 Final follow-up radiographs. Anteroposterior and lateral radiographs of the elbow in a nine-year-old girl with transphyseal fracture of the distal humerus (TFDH) treated by open reduction at the age of 15 months (**a** and **b**) and a 42-month-old boy with TFDH treated by closed reduction at the age of 37 months (**c** and **d**)

diagnosed on plain radiographs in 11 out of 16 patients. In the remaining five, diagnosis was suspected on plain radiographs and later confirmed by MRI. Plain AP radiographs usually highlight the malalignment between the distal humerus and the proximal ulna and radius, most frequently medial (14 cases out of 16 in our series; 87.5%). On the other hand, L radiographs usually show a reduction of the gap between the proximal anterior humeral line and the radial metaphysis with posterior displacement of the elbow joint.[13,29] In our series all fractures were displaced posteriorly and TFDH could be suspected on plain radiographs in all patients.

Elbow ultrasound and MRI have also been shown to be valid options to diagnose TFDH in doubtful cases. Brown and Eustace,[29] Dias et al[30] and Supakul et al[15] noted that ultrasound is relatively inexpensive compared with MRI; it is non-invasive and it does not require sedation. However, elbow joint ultrasound could not be performed on any of our patients due to pain and significant elbow swelling. Although it requires sedation, MRI is another option to assess TFDH as it provides a larger field of view and multi-planar images as well as the possibility to assess postoperative distal humerus physeal status during follow-up, as showed by Nimkin et al.[31] In our series, MRI was performed in five patients to confirm the diagnosis of TFDH suspected on plain radiographs (Fig. 1).

On the other hand, the arthrogram is a useful tool that can help the surgeon not only to confirm the diagnosis but also to assess the quality of the reduction that appears to be the main factor influencing outcome. Tharakan et al[32] reported about the use of intraoperative elbow joint arthrogram to ensure proper reduction and stabilization of the fracture. In our series, intraoperative elbow joint arthrogram was performed in one patient only, as we consider that the main role of intraoperative arthrogram is to assess the quality of the reduction of the fracture in all planes, especially in doubtful cases (Fig. 6).

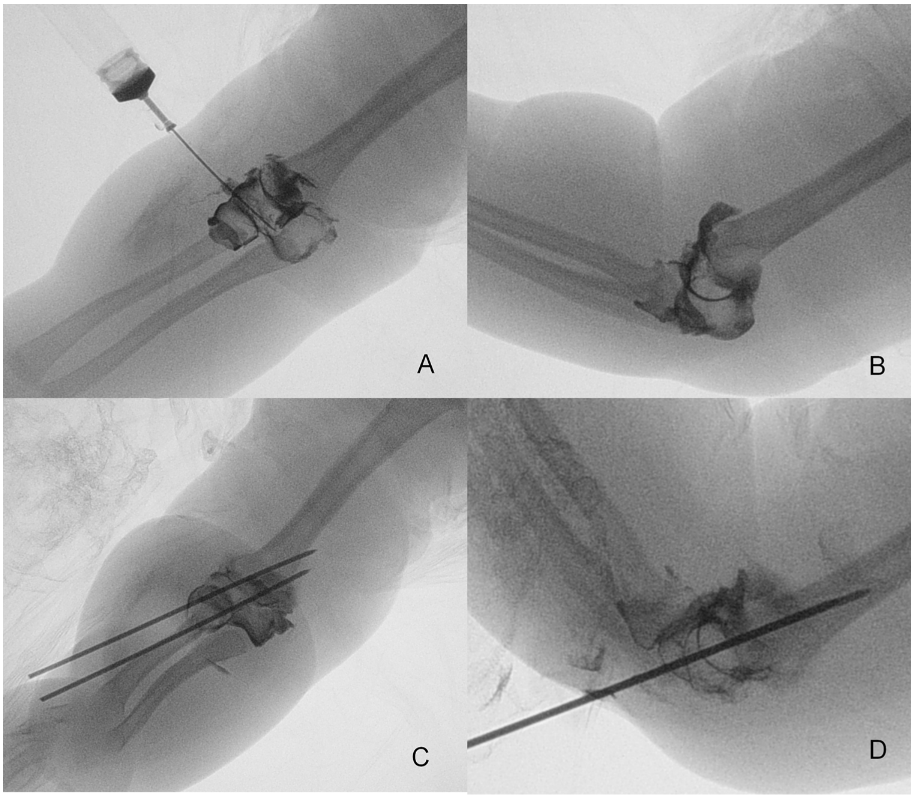

Fig. 6 Pre- and postoperative elbow joint arthrogram of an 18-month-old girl with transphyseal fracture of the distal humerus. Preoperative arthrogram shows medial (**a**) and posterior (**b**) displacement of the distal fragment; postoperative images show a good reduction of the fracture on both frontal and sagittal plane (**c** and **d**).

We encountered some limitations in the analysis of our results. First, while there is no set age limit, the MEPS scale was developed for adults and it is not a validated outcome measure in children. However, only patients older than four years of age were included and were able to understand the question and answer independently. Additionally, the MEPS has already been used to measure symptom severity and disability in a variety of upper extremity fractures in children.[16,17] Previous reports provided a support to applying MEPS questionnaire in children, but further studies are needed to demonstrate its reliability in the paediatric population.

Secondly, this is a retrospective study with a relatively low number of patients. However, due to the rarity of the lesion, it is one of the largest series available[12,15,19] and the only one that assesses injured elbow function with a reproducible and validated grading system and compares it with the non-injured side, used as control group. Additionally, the patients formed a homogeneous group in terms of age and type of fracture.

Thirdly, several tools, such as the QuickDash[33] and the Pediatric Outcomes Data Collection Instrument[34] score have been developed to evaluate upper extremity and elbow function in children. However, due to the relatively long time needed to properly fill in both questionnaires, we chose the MEPS questionnaire which has likewise been applied to children, although it has not yet been validated in the paediatric population.

In conclusion, our study reports good functional outcome in toddlers with TFDH surgically treated, provided that optimal reduction is achieved, as patients treated by closed or open reduction show similar functional outcome irrespective of the type of fracture. However, a residual cubitus varus was commonly observed among these patients.

Received 12 September 2018; accepted after revision 03 December 2018.

COMPLIANCE WITH ETHICAL STANDARDS

FUNDING STATEMENT

No benefits in any form have been received or will be received from a commercial party related directly or indirectly to the subject of this article.

ETHICAL STATEMENT

Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. This article does not contain any studies with animals performed by any of the authors.

Informed consent: Not required for this work.

ICMJE CONFLICT OF INTEREST STATEMENT

All authors declare that they have no conflict of interest.

AUTHOR CONTRIBUTIONS

W. Zhou: data acquisition, analysis and interpretation of data, writing of the manuscript.

F. Canavese: critical revision of the manuscript.

L. Zhang: data acquisition, interpretation of data.

L. Li: study design, critical revision of the manuscript.

REFERENCES

1. **Abzug JM, Ho CA, Ritzman TF, Brighton BK.** Transphyseal fracture of the distal humerus. *J Am Acad Orthop Surg* 2016;24:e39-e44.

2. **Peterson HA.** *Epiphyseial growth plate fractures.* Berlin, Germany: Springer-Verlag Berlin Heidelberg, 2007.

3. **Kaplan SS, Reckling FW.** Fracture separation of the lower humeral epiphysis with medial displacement. Review of the literature and report of a case. *J Bone Joint Surg [Am]* 1971;53-A:1105-1108.

4. **Mizuno K, Hirohata K, Kashiwagi D.** Fracture-separation of the distal humeral epiphysis in young children. *J Bone Joint Surg [Am]* 1979;61-A:570-573.

5. **Jacobsen S, Hansson G, Nathorst-Westfelt J.** Traumatic separation of the distal epiphysis of the humerus sustained at birth. *J Bone Joint Surg [Br]* 2009;91-B:797-802.

6. **Kamaci S, Danisman M, Marangoz S.** Neonatal physeal separation of distal humerus during cesarean section. *Am J Orthop* 2014;43:E279-E281.

7. **Berman JM, Weiner DS.** Neonatal fracture-separation of the distal humeral chondroepiphysis: a case report. *Orthopedics* 1980;3:875-879.

8. **Oda R, Fujiwara H, Ichimaru K, et al.** Chronic slipping of bilateral distal humeral epiphyses in a gymnastist. *J Pediatr Orthop B* 2015;24:67-70.

9. **Kay M, Simpkins C, Shipman P, Whitewood C.** Diagnosing neonatal transphyseal fractures of the distal humerus. *J Med Imaging Radiat Oncol* 2017;61:494-499.

10. **Beckmann NM, Crawford L.** Salter-Harris I fracture of the distal humerus in a neonate: imaging appearance of radiographs, ultrasound, and arthrography. *Radiol Case Rep* 2017;12:571-576.

11. **de Jager LT, Hoffman EB.** Fracture-separation of the distal humeral epiphysis. *J Bone Joint Surg [Br]* 1991;73-B:143-146.

12. **Abe M, Ishizu T, Nagaoka T, Onomura T.** Epiphyseal separation of the distal end of the humeral epiphysis: a follow-up note. *J Pediatr Orthop* 1995;15:426-434.

13. **Gilbert SR, Conklin MJ.** Presentation of distal humerus physeal separation. *Pediatr Emerg Care* 2007;23:816-819.

14. **McIntyre WM, Wiley JJ, Charette RJ.** Fracture-separation of the distal humeral epiphysis. *Clin Orthop Relat Res* 1984;188:98-102.

15. **Supakul N, Hicks RA, Caltoum CB, Karmazyn B.** Distal humeral epiphyseal separation in young children: an often-missed fracture-radiographic signs and ultrasound confirmatory diagnosis. *AJR Am J Roentgenol* 2015;204:W192-198.

16. **Cook JB, Riccio AI, Anderson T, et al.** Outcomes after surgical treatment of adolescent intra-articular distal humerus fractures. *J Pediatr Orthop* 2016;36:773-779.

17. **Tarallo L, Mugnai R, Fiacchi F, Capra F, Catani F.** Management of displaced radial neck fractures in children: percutaneous pinning vs. elastic stable intramedullary nailing. *J Orthop Traumatol* 2013;14:291-297.

18. **Morrey BF, Adams RA.** Semiconstrained arthroplasty for the treatment of rheumatoid arthritis of the elbow. *J Bone Joint Surg [Am]* 1992;74-A:479-490.

19. **DeLee JC, Wilkins KE, Rogers LF, Rockwood CA.** Fracture-separation of the distal humeral epiphysis. *J Bone Joint Surg [Am]* 1980;62-A:46-51.

20. **Oh CW, Park BC, Ihn JC, Kyung HS.** Fracture separation of the distal humeral epiphysis in children younger than three years old. *J Pediatr Orthop* 2000;20:173-176.

21. **Navallas M, Díaz-Ledo F, Ares J, et al.** Distal humeral epiphysiolysis in the newborn: utility of sonography and differential diagnosis. *Clin Imaging* 2013;37:180-184.

22. **Yoo CI, Suh JT, Suh KT, et al.** Avascular necrosis after fracture-separation of the distal end of the humerus in children. *Orthopedics* 1992;15:959-963.

23. **Holda ME, Manoli A, LaMont RI.** Epiphyseal separation of the distal end of the humerus with medial displacement. *J Bone Joint Surg [Am]* 1980;62-A:52-57.

24. **Tudisco C, Mancini F, De Maio F, Ippolito E.** Fracture-separation of the distal humeral epiphysis. Long-term follow-up of five cases. *Injury* 2006;37:843-848.

25. **Dimeglio A.** Growth in pediatric orthopaedics. *J Pediatr Orthop* 2001;21:549-555.

26. **Peiro A, Mut T, Aracil J, Martos F.** Fracture-separation of the lower humeral epiphysis in young children. *Acta Orthop Scand* 1981;52:295-298.

27. **Rogers LF, Rockwood CA.** Separation of the entire distal humeral epiphysis. *Radiology* 1973;106:393-400.

28. **Cusick MC, Bonnaig NS, Azar FM, et al.** Accuracy and reliability of the Mayo Elbow Performance Score. *J Hand Surg Am* 2014;39:1146-1150.

29. **Brown J, Eustace S.** Neonatal transphyseal supracondylar fracture detected by ultrasound. *Pediatr Emerg Care* 1997;13:410-412.

30. **Dias JJ, Lamont AC, Jones JM.** Ultrasonic diagnosis of neonatal separation of the distal humeral epiphysis. *J Bone Joint Surg [Br]* 1988;70-B:825-828.

31. **Nimkin K, Kleinman PK, Teeger S, Spevak MR.** Distal humeral physeal injuries in child abuse: MR imaging and ultrasonography findings. *Pediatr Radiol* 1995;25:562-565.

32. **Tharakan SJ, Lee RJ, White AM, Lawrence JT.** Distal humeral epiphyseal separation in a newborn. *Orthopedics* 2016;39:e764-e767.

33. **Beaton DE, Wright JG, Katz JN.** Development of the QuickDash: comparison of three item-reduction approaches. *J Bone Joint Surg [Am]* 2005;87-A:1038-1046.

34. **Daltroy LH, Liang MH, Fossel AH, Goldberg MJ.** The POSNA pediatric musculoskeletal functional health questionnaire: report on reliability, validity, and sensitivity to change. Pediatric Outcomes Instrument Development Group. Pediatric Orthopaedic Society of North America. *J Pediatr Orthop* 1998;18:561-571.