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Original Article

Comparison of Kirschner wires and Orthofix® external fixator for displaced supracondylar humerus fractures in children

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Abstract: *Objective*: Closed reduction and percutaneous fixation is known as the optional treatment for displaced supracondylar humerus fractures. The retrospective study is to compare external fixator versus K-wires to evaluate the clinical and radiological results for displaced supracondylar humerus fractures. *Methods*: Among all of 40 patients, there were 16 girls and 24 boys with the mean age of 7.26 years (range from 4 to 13 years). Closed reduction followed by percutaneous fixation of external fixator or K-wires were performed in our department. Medical records were reviewed to obtain demographic information as well as preoperative and postoperative clinical and radiological data regarding fracture type, displacement of fracture, neurovascular status, range of motion and infections. The Flynn's criteria et al. was used to evaluate the clinical outcomes. *Results*: There was no significant different in age, gender, affected sides, the type and displacement of fracture and nerve palsy between two group (P>0.05). According to the Flynn's criteria et al., two groups showed the similar to clinical outcome (P>0.05). Two (13.3%) children presented skin infection around screws, while five (20%) patients presented skin infection in K-wires, in which four (80%) patients develop the migration of K-wires. There was significant different in skin infection between two groups. Three (12%) patients presented ulnar nerve palsy in K-wires, while one (6.7%) patient presented radial nerve palsy in external fixator. *Conclusion*: The percutaneous K-wires or external fixator fixation following closed reduction is an effective method in the treatment of displaced supracondylar fractures of humerus. K-wires have the risk of ulnar nerve palsy and skin infection or the migration of wires. External fixator could facilitate to reduce the fracture by the direct manipulation of external fixing frame and provide the stabilization of fracture without the neurological risk to ulnar nerve.

Keywords: Supracondylar humeral fractures, infection, children, closed reduction, percutaneous pinning, supracondylar fractures of the distal humerus

Introduction

The Supracondylar fractures of the distal humerus is the most common fracture around the elbow in children [1]. It is well known that percutaneous K-wires following reduction of fracture segment and is an optional method in treatment of supracondylar humeral fractures [2]. Those previous studies showed that two crossed Kirschner wires (K-wires) could provide excellent stability of fracture with success clinical results [3]. However, the iatrogenic injury of ulnar nerve was commonly reported so as to the other alternative configurations [4]. Lee et al. [5] reported that the fixation of three lateral K-wires could provide the stability of fracture and avoid the ulnar nerve injury for supracondylar humeral fractures. Aleksandra et al. [6] reported that humero-ulnar external fixation provided the similar effective with lateral or crossed K-wires in treatment for supracondylar humeral fractures. Hohloch et al. [7] reported that a lateral anti-rotation K-wires combined with external fixator could reduce the displacement of supracondylar humerus fractures with success clinical results. However,

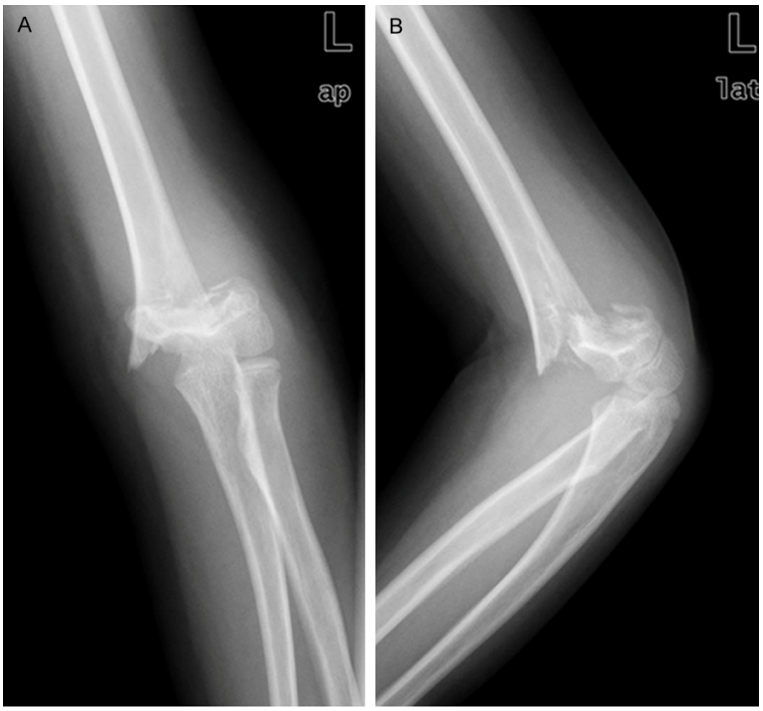

Figure 1. The anteroposterior (A) and lateral radiographs (B) showed the significant displaced supracondylar humerus fracture with the rotational deformity.

there was no previous study in comparing the fixation of K-wires to external fixator in supracondylar humerus fracture.

In our department, we performed the percutaneous fixation of K-wires (a medial and two or three lateral) or Orthofix® external fixator following the close reduction as the treatment in supracondylar humerus fractures. In the present study, we retrospectively reviewed cases of supracondylar humerus fractures treated with K-wires or external fixator. The purpose of study was to evaluate the clinical outcomes and the characteristics of two groups in the treatment of displaced supracondylar humerus fractures in children.

Patients and methods

Between January 2006 to December 2012, 40 children with supracondylar humerus fractures was performed in the retrospective study. Radiological examinations of bilateral elbows at injury were analyzed for displacement and fracture patterns. Indications for treatment were determined according to fracture type. The Gartland classification was used to classify the type of fracture. Gartland type I and type-IIA fracture with the posterior cortex intact and the capitellum posterior to its normal intersection with the anterior humeral line were excluded from the study. Gartland type-IIB (a straight or rotatory displacement in fracture with the contact of fragments) and type-III fractures (completely displaced fractures without of cortex intact) were treated by external fixator or different K-wires fixation following the closed reduction.

The anteroposterior and lateral radiographs was performed in all patients (**Figure 1**). The demographic information, clinical data and treatment were obtained and recorded. The information of cases including cases, gender, mea age at injury, fracture type and displacement, nerve plasy and anaesthesia methods were recorded in clinical characteristics of patients (**Table 1**).

Surgical technique

The informed consent from patients and patients' parents or guardians was obtained. After child was performed by general or brachial plexus anaesthesia, the fluoroscopy with X-ray was performed during the operation. The fracture with overlapping deformity was firstly reduction by against pull, and then lateral displacement was gradually reduction. The significant flexion position of elbow was maintained in order to avoid the displacement of fracture by assistant. The lateral fluoroscopy showed the anterior line of the humerus passed through the middle third of capitulum humeri with normal of Baumann angle.

In group of K-wires, two or three lateral K-wires (1.0, 1.5 or 2.0 mm) were inserted in lateral condyle of humerus and medial column with achieving maximum separation. Medial K-wires was inserted in the epicondylus medialis humeri to reduce the risk of iatrogenic nerve injury, and then pass through lateral column.

Table 1. Clinical characteristics of children with displaced supracondylar humerus fractures based on the type of treatment

Parameter		Kirschner wires	External fixator	P
Number		25	15	-
Gender, n (%)	Boy	15 (60%)	10 (66.7%)	0.04
	Girl	10 (40%)	5 (33.3%)	
Mean age at injury (years)		7.69±2.41	7.00±1.80	0.32
Affected side, n (%)	Right	16 (64%)	10 (66.7%)	0.86
	Left	9 (36%)	5 (33.3%)	
Fracture Type	Gartland IIB	7 (28%)	4 (26.7%)	0.48
	Gartland III	18 (72%)	11 (73.3%)	
Displacement	Posteriomedial	14 (77.1%)	8 (57.1%)	0.19
	Posteriolateral	11 (22.9%)	7 (42.9%)	
Nerve Plasy	Median nerve	1 (2.9%)	1 (5.8%)	0.65
	Radial nerve	1 (2.9%)	1 (2.9%)	
	Ulnar nerve	1	0 (2.9%)	
Anaesthesia	General	12 (82.9%)	7 (71.4%)	0.50
	Regional	13 (17.1%)	8 (28.6%)	
Complications	Skin infection	5 (20%)	2 (13.3%)	0.001
	Ulnar nerve palsy	3 (12%)	0	0.001
	Radial nerve palsy	0	1 (6.7%)	

Table 2. Flynn's criteria for functional and cosmetic factors of supracondylar humeral fracture treatment

Results	Rating	Functional factor: loss of range of motion (°)	Cosmetic factor: loss in carrying angle (°)
Satisfactory	Excellent	0-5	0-5
	Good	5-10	5-10
	Fair	10-15	10-15
Unsatisfactory	Poor*	>15	>15

*The lower of the two ratings and the elbow with a varus deformity is automatically graded as poor.

The size of K-wires was on the basis of the width of humeri, and K-wires through the olecranon fossa were acceptable. In lateral radiographs, K-wires were inserted in an incline direction to recovery the normal of Baumann angle. In anteroposterior radiographs, K-wires should be maximally separated the proximal of fracture and inserted into the medial humerus cortex in order to maintain the stability of fracture. When medial K-wires caused neurological symptoms of ulnar nerve, it will be extracted with the stability of fracture maintained by the residual of lateral K-wires.

In group of external fixator, after the fracture was closed reduction, the first screw was inserted into the osteoepiphysis of capitulum humeri and perpendicular to the axis of humerus. The second screw in distal fracture was parallel to the first screw. Both screws pass through the middle metaphysis of distal end of humerus and were fixed to external fixing frame. The other two screws were inserted in the proximal of fracture, pass through the contralateral cortex and fixed in the predesigned position in external fixing frame. The external fixing frame was adjusted to reduce the fracture to recover the normal Baumann angle. The direction loading in varus, valgus, flexion or extension was used to evaluate the stability of fracture under fluoroscopy. Skin care was performed in order to avoid the infection of K-wires and screws. After the fixation of plaster cast for 4 weeks, patients were encouraged to do the active range of motion. K-wires and screws were percutaneous removed in clinic under local anaesthesia.

Clinical and radiographic assessments were performed to evaluate the efficiency of fixation with K-wires and external fixator. Clinical evaluations for pain, skin infection and flexion and extension angle of elbow were also performed. Complications including neurologic injury (motor and/or sensory deficits), skin or deep infection, vascular injury, nonunion and malunion were recorded and assessed. Radiographs of elbow were performed to estimate the radiological outcome of fracture including carrying angle and the relationship of the capitulum humeri and the anterior of shaft of humerus. Flynn's criteria with "functional" and "cosmetic" were performed to evaluate the clinical outcomes. The clinical outcomes were classified by the degrees including the excellent with 0-5, good

Figure 2. Radiographs showed a displaced supracondylar humerus fracture (A and B). The fracture was closed reduction and percutaneous fixed by smooth K-wires (one medial and two lateral) after surgery (C and D). The fracture was gradually healed with bone callus after five weeks of surgery (E and F). The follow-up radiographs showed the complete union of fracture without cubitus varus (G and H).

with 6-10, fair with 11-15 and unsatisfactory or poor score >15 degrees [8] (**Table 2**).

Statistical analysis

All data are expressed as mean ± standard error of the mean (SEM) unless otherwise stated. Pearson's chi-squared test was used to compare general data and the condition of supracondylar humerus fractures between the two treatment groups. Fisher's exact test was used for theoretical samples of less than five. *P* values <0.05 were considered statistically significant. Kappa values were used to determine intraobserver and interobserver repeatability and reliability. All statistical calculations were performed using commercially available statistical software (IBM SPSS Statistics version 22).

Results

During the last follow-up, the follow-up period was ranging from 23 to 78 months with the mean of 37.5 months. In group of K-wires fixation, 25 patients were treated by a medial K-wires and two lateral K-wires (18 fractures, 72%) or three lateral K-wires (7 fractures, 28%). There were 15 (60%) boys and 10 (40%) girls and 16 (64%) in right side and 9 (36%) in left sides. The median age was 7.00±1.80 years (range 4~12 years). According to Gartland classification, there were 7 (28.0%) in Gartland IIB and 18 (72.0%) in Gartland III. There was a child with high median nerve palsy, one in radi-

Figure 3. Radiographs showed a displaced supracondylar humerus fracture in right elbow (A and B). The fracture was closed reduction and percutaneous fixed by smooth K-wires (one medial and three laterals) after surgery (C and D). The fracture was gradually healed and the smooth K-wires were extracted after seven weeks of surgery (E and F). The follow-up radiographs showed the complete union of fracture without cubitus varus (G and H).

al nerve palsy and one in ulnar nerve (**Figures 2** and **3**).

In group of 15 patients treated by external fixator fixation, there were 10 (66.7%) boys and 5 (33.3%) girls and 10 (66.7%) in right side and 5 (33.3%) in left sides. The median age was 7.69±2.41 years (range 4~12 years). There were 4 (26.7%) in Gartland IIB and 11 (73.3%) in Gartland III. One child had signs of high median nerve palsy and one in radial nerve palsy. There was no significant different in gender, affected side, age at injury and displacement between the fixation of K-wires and external fixator ($p>0.05$) (**Figure 4**).

In the follow-up of two groups, the angles of flexion, extension and carrying angle of both elbows were recorded to evaluate the clinical results (**Table 3**). The affected elbow in both groups showed that the angles of mean flexion decrease and the angles of extension increase compared to normal side. Both groups showed that the loss of carrying angle was significant different between the affected and normal side. The final follow-up showed that it was no significant different in different of extension, flexion and carrying angle between two groups ($P>0.05$).

According to Flynn's classification, in group of K-wires, the functional result was excellent in 20 (80.0%) children, good in 3 (12.0%), fair in 1 (4.0%) and poor in 1 (4.0%) patients; the cosmetic result was excellent in 18 (72.0%) patients and good in 4 (16.0%), fair in 2 (8.0%) and poor 1 (4.0%). In group of external fixator, the functional result was excellent in 12 (80.0%) patients, good in 2 (13.3%) and fair in 1 (6.7%) patients; the cosmetic result was excellent in 11 (73.3%) patients and good in 2 (13.3%), fair

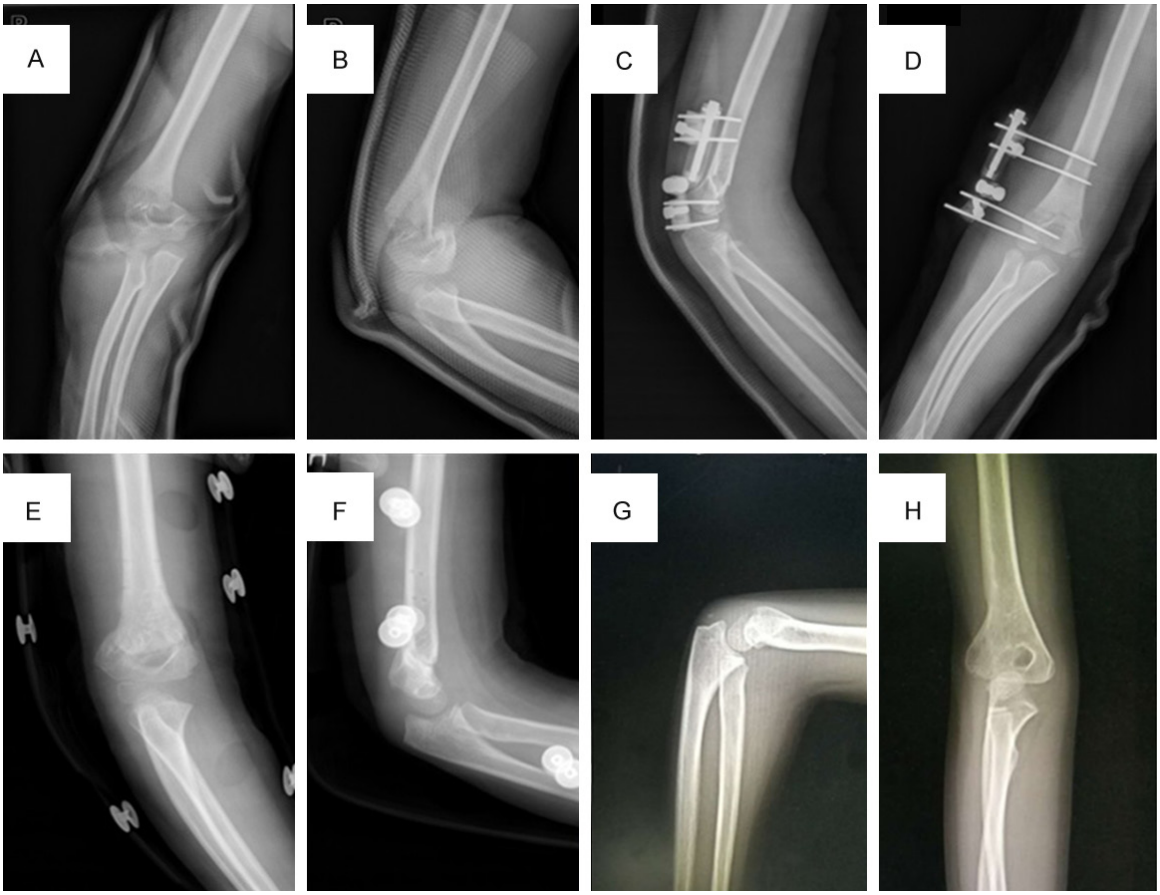

Figure 4. Radiographs showed a displaced supracondylar humerus fracture in elbow (A and B). The fracture was closed reduction and percutaneous fixed by external fixator and four screws after surgery (C and D). After the fracture was union, external fixator was extracted with orthosis (E and F). The follow-up radiographs showed the complete union of fracture without cubitus varus (G and H).

Table 3. Comparison of motion function of affected elbow and normal elbow between the K-wires and external fixator group in treatment for supracondylar humerus fractures (Mean ± standard deviation)

Parameter	K-wires		External fixator		P*
	Affected	Normal	Affected	Normal	
Flexion	133.72±4.25	136.08±3.64	133.13±3.96	136.73±3.31#	0.64
Extension	0.04±3.53	-4.48±3.76†,#	-0.46±2.92†	-3.87±4.27†,#	0.52
Carrying angle	5.36±4.51	12.28±2.19#	5.67±4.09	12.13±2.72#	0.22

†Negative value for extension indicates recurvatum; #Means the significant different between the affected side and normal side; *The statistical analysis in the angle with different of the affected side and normal side between two groups.

in 1 (6.7%) and poor in 1 (6.7%) (**Table 4**). According to Flynn's classification system, there was no statistical difference in the clinical outcome between K-wires and external fixator (P>0.05).

Complications in two groups were recorded. Two (13.3%) children presented skin infection around screws, while five (20%) patients presented skin infection in K-wires, in which four (80%) patients develop the migration of K-wires. Local wound, oral antibiotics and the orthosis of elbow was used in the treatment of prevent skin infection to avoid the migration of K-wires and screws. After a week, skin infection was cured. All fractures successfully were union at final follow-up. Those were migrated around bone hole, and even extracted the

Table 4. The clinical outcome of displaced supracondylar fractures with different treatments

Clinical outcome		K-wires	External fixator	p
Functional factor: loss of range of motion (°)	Excellent	20 (80.0%)	12 (80.0%)	0.392
	Good	3 (12.0%)	2 (13.3%)	
	Fair	1 (4.0%)	1 (6.7%)	
	Poor	1 (4.0%)	0 (0.0%)	
Cosmetic factor: loss in carrying angle (°)	Excellent	18 (72.0%)	11 (73.3%)	0.215
	Good	4 (16.0%)	2 (13.3%)	
	Fair	2 (8.0%)	1 (6.7%)	
	Poor	1 (4.0%)	1 (6.7%)	

humerus in two patients. No patients in two groups presented vascular injury, compartment syndrome, deep infection and nonunion.

Three (12%) patients presented ulnar nerve palsy in K-wires, and medial K-wire was removed immediately. The duration of plaster cast increased to 6 weeks, and nerve palsy gradually recovered with completely union of fracture. One (6.7%) patient presented radial nerve palsy instead of ulnar nerve palsy in external fixator with gradual recover at three months follow-up. All patients had symmetrical and normal functions in flexion-extension of elbow. One patient in group of K-wires developed cubitus varus with carrying angle of -10° in varus. The flexion-extension and supination range of motion were normal with less than 20° active pronation. The additional surgery of supracondylar humerus osteotomy was performed to improve the cubitus varus.

Discussion

The supracondylar humeral fracture is the most common fracture in the elbow of children. Among the supracondylar fractures, type IIB and type III account for approximately two fifth of these injuries. The goal of treatment is the anatomical reduction and different fixations to avoid the displacement of fracture and angular deformity. In this retrospective study, we reviewed cases of displaced supracondylar humerus fractures to evaluate K-wires or external fixator in clinical and radiological outcomes in children. According to Flynn's classification system, it was no statistically difference in clinical outcomes between both groups (P>0.05). All fractures in two groups were union at last follow up.

Since 1948, Swenson described two K-wires of different sizes for closed reduction in supracondylar humerus fractures [9]. It could promote the anatomical reduction of fracture to allow the elbow in less than 90 degree of flexion. Those previous studies have shown the effectiveness of the crossed, two or three lateral divergent, a medial and two or three lateral divergent, humero-ulnar external fixation and lateral external fixation [10]. Besides, biomechanical studies have demonstrated the stability of lateral and medial column for supracondylar humerus fractures with different fixation of K-wires or extra fixation [7, 10, 11]. Arino et al. [12] reported that two lateral K-wires in fracture in parallel or divergent pattern could reduce the iatrogenic ulnar nerve injury. Srikumaran et al. [13] reported that K-wires in two lateral with 1 medial configuration provided more stable reduction than the two K-wires in a lateral divergent configuration.

In our department, we recommended one medial and two or three lateral K-wires and Orthofix external fixator in supracondylar humerus fractures. In present study, there were 7 (28%) in Gartland IIB and 18 (72%) in Gartland III in group of K-wires and 4 (26.7%) in Gartland IIB and 11 (73.3%) in group of external fixator. Evaluation at clinical characteristics of patients showed that there was no significant different in gender, affected side, age at injury and displacement between the fixation of K-wires and external fixator (P>0.05). At final follow-up, all fracture in two groups were union without nonunion. Flynn's criteria is a common principle in evaluating the functional and cosmetic outcomes in children [3]. The principle could evaluate the functional outcomes and cosmetic results in separate form, as some cases with deformity may have normal func-

tion of elbow [14, 15]. In group of K-wires, the functional result was excellent in 20 (80.0%) children, good in 3 (12.0%), fair in 1 (4.0%) and poor in 1 (4.0%) patients; the cosmetic result was excellent in 18 (72.0%) patients and good in 4 (16.0%), fair in 2 (8.0%) and poor 1 (4.0%). In group of external fixator, the functional result was excellent in 12 (80.0%) patients, good in 2 (13.3%) and fair in 1 (6.7%) patients; the cosmetic result was excellent in 11 (73.3%) patients and good in 2 (13.3%), fair in 1 (6.7%) and poor in 1 (6.7%). According to Flynn's classification system, it was no statistical difference in clinical results of two groups ($P > 0.05$). In Slongo et al. [16] study, the cosmetic result in all patients was excellent, and all patients except one had good range of movement in affected elbow. Basaran et al. reported that according to Flynn's criteria, 32 (88.9%) in 36 patients presented excellent and good functional results by closed reduction and K-wires fixation [17].

One medial combined two or three K-wires could provide more stability than classical crossed, two or three lateral divergent of K-wires in complex supracondylar humeral fractures in children [13]. Silva et al. [18] reported two lateral adding a medial K-wires increased torsional stiffness and bending stiffness. Zionts et al. [19] demonstrated that two crossed K-wires fixation could provide more stable torsional fixation than three lateral K-wires, which was similar to the result in Lee et al. study [20]. In our study, the configuration of K-wires also provided the stability of supracondylar humeral fractures. Compared with fixation of K-wires, the reduction of fracture can be facilitated by direct manipulation of external fixing frame. If the reduction is not optimal with residual extend displacement, external fixing could reduce the fracture easily in vertical plane. Slongo et al. [16] reported external fixator as a safe alternative for supracondylar fractures of humerus, and the manipulation of external fixator could reduce the unattainable fracture. The external fixator facilitated a satisfactory reduction of fracture by an indirect approach and provided the rigid stability of fracture to allow early movement of elbow without additional plaster immobilization [21].

Ulnar nerve injury is a common complication if K-wires is inserted in medial direction. Those previous studies reported that ulnar nerve injury caused by medial K-wires ranges from 1.4% to 15.6% [22]. In our study, medial K-wire was inserted through the epicondylus medialis humeri to avoid ulnar nerve palsy. However, ulnar nerve palsy developed in three (12%) patients. After K-wire was extracted, nerve palsy was gradually recovered. In previous studies, the medial K-wires could increase the risk of ulnar nerve injury compared with lateral K-wires fixation [23, 24]. Besides, Brauer et al. [25] concluded that the risk of ulnar nerve injury was higher that two crossed K-wires than that with lateral-only K-wires. After K-wire was extracted as ulnar nerve palsy, the stability for fracture depends on the residual two or three K-wires. In group of external fixator, screws were inserted in lateral of humeral without ulnar nerve injury. However, external screws bring its own risks of nerve injury with potentially injury of radial nerve. When screws were inserted into the posterior aspect in proximal fracture of humerus, radial nerve at the site may be injury. Therefore, the proximal screw was just above the fracture in order to reduce the risk of radial nerve injury and promote the stability of fracture.

Skin infection was another common complication in percutaneous reduction of fracture. In our study, two (13.3%) children presented skin infection around screws, while five (20%) patients presented skin infection in K-wires. Local wound care and oral antibiotics were effective for skin infection. However, in some cases with infection, K-wires were migrated in bone hole and even extracted from humerus, which may cause the loss of reduction. Therefore, we recommended plaster splinting in cases of skin infection to prevent the migration of K-wires and loss of reduction. There was no case presented the migration of screws or extraction from humerus in group of external fixator.

In this article, we evaluated the clinical and radiological outcome for the displaced supracondylar humerus fractures by external fixator or K-wires. However, it is not a prospective, randomized study in comparing with external fixator or K-wires. Besides, it was clinical trial of supracondylar humerus fractures. We will evaluate the biomechanical analysis of the stability of external fixator or K-wires for stabilizing supracondylar humerus fractures.

Conclusions

Closed reduction followed by percutaneous K-wires (one medial and two or three lateral) or external fixator fixation is an effective treatment in the displaced supracondylar humeral fracture in children. K-wires and external fixator provided stability of fracture and allowed the early mobilization of elbow joint. K-wires have the risk of skin infection with result of migration or extraction of wires and medial ulnar nerve palsy, but a longer period of plaster splinting is required. The reduction of fracture could be facilitated by direct manipulation of external fixing frame, and screws in humerus could obtain good stabilisation of the fracture with moderate elbow flexion the absence of neurological risk to the ulnar nerve.

Disclosure of conflict of interest

None.

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References

[1] Cheng JC, Lam TP and Shen WY. Closed reduction and percutaneous pinning for type III displaced supracondylar fractures of the humerus in children. J Orthop Trauma 1995; 9: 511-515.

[2] El-Adl WA, El-Said MA, Boghdady GW and Ali AS. Results of treatment of displaced supracondylar humeral fractures in children by percutaneous lateral cross-wiring technique. Strategies Trauma Limb Reconstr 2008; 3: 1-7.

[3] Zorrilla S de Neira J, Prada-Canizares A, Marti-Ciruelos R and Pretell-Mazzini J. Supracondylar humeral fractures in children: current concepts for management and prognosis. Int Orthop 2015; 39: 2287-2296.

[4] Zamzam MM and Bakarman KA. Treatment of displaced supracondylar humeral fractures among children: crossed versus lateral pinning. Injury 2009; 40: 625-630.

[5] Lee YH, Lee SK, Kim BS, Chung MS, Baek GH, Gong HS and Lee JK. Three lateral divergent or parallel pin fixations for the treatment of displaced supracondylar humerus fractures in children. J Pediatr Orthop 2008; 28: 417-422.

[6] Bogdan A, Quintin J and Schuind F. Treatment of displaced supracondylar humeral fractures in children by humero-ulnar external fixation. Int Orthop 2016; 40: 2409-2415.

[7] Hohloch L, Konstantinidis L, Wagner FC, Strohm PC, Sudkamp NP and Reising K. Biomechanical comparison of different external fixator configurations for stabilization of supracondylar humerus fractures in children. Clin Biomech (Bristol, Avon) 2016; 32: 118-123.

[8] Flynn JC, Matthews JG and Benoit RL. Blind pinning of displaced supracondylar fractures of the humerus in children. Sixteen years' experience with long-term follow-up. J Bone Joint Surg Am 1974; 56: 263-272.

[9] Swenson AL. The treatment of supracondylar fractures of the humerus by Kirschner-wire transfixion. J Bone Joint Surg Am 1948; 30A: 993-997.

[10] Bloom T, Robertson C, Mahar AT and Newton P. Biomechanical analysis of supracondylar humerus fracture pinning for slightly malreduced fractures. J Pediatr Orthop 2008; 28: 766-772.

[11] Ducic S, Bumbasirevic M, Radlovic V, Nikic P, Bukumiric Z, Brdar R, Radojicic Z, Bukva B, Abramovic D and Ducic TJ. Displaced supracondylar humeral fractures in children: comparison of three treatment approaches. Srp Arh Celok Lek 2016; 144: 46-51.

[12] Arino VL, Lluch EE, Ramirez AM, Ferrer J, Rodriguez L and Baixauli F. Percutaneous fixation of supracondylar fractures of the humerus in children. J Bone Joint Surg Am 1977; 59: 914-916.

[13] Srikumaran U, Tan EW, Belkoff SM, Marsland D, Ain MC, Leet AI, Sponseller PD and Tis JE. Enhanced biomechanical stiffness with large pins in the operative treatment of pediatric supracondylar humerus fractures. J Pediatr Orthop 2012; 32: 201-205.

[14] Madjar-Simic I, Talic-Tanovic A, Hadziahmetovic Z and Sarac-Hadzihalilovic A. Radiographic assessment in the treatment of supracondylar humerus fractures in children. Acta Inform Med 2012; 20: 154-159.

[15] Moraleda L, Valencia M, Barco R and Gonzalez-Moran G. Natural history of unreduced Gartland type-II supracondylar fractures of the humerus in children: a two to thirteen-year follow-up study. J Bone Joint Surg Am 2013; 95: 28-34.

[16] Slongo T, Schmid T, Wilkins K and Joeris A. Lateral external fixation--a new surgical technique for displaced unreducible supracondylar humeral fractures in children. J Bone Joint Surg Am 2008; 90: 1690-1697.

[17] Basaran SH, Ercin E, Bayrak A, Bilgili MG, Kizilkaya C, Dasar U and Avkan MC. The outcome and parents-based cosmetic satisfaction following fixation of paediatric supracondylar humerus fractures treated by closed

method with or without small medial incision. Springerplus 2016; 5: 174.
[18] Silva M, Knutsen AR, Kalma JJ, Borkowski SL, Bernthal NM, Spencer HT, Sangiorgio SN and Ebramzadeh E. Biomechanical testing of pin configurations in supracondylar humeral fractures: the effect of medial column comminution. J Orthop Trauma 2013; 27: 275-280.
[19] Zionts LE, McKellop HA and Hathaway R. Torsional strength of pin configurations used to fix supracondylar fractures of the humerus in children. J Bone Joint Surg Am 1994; 76: 253-256.
[20] Lee SS, Mahar AT, Miesen D and Newton PO. Displaced pediatric supracondylar humerus fractures: biomechanical analysis of percutaneous pinning techniques. J Pediatr Orthop 2002; 22: 440-443.
[21] Slongo T. [Radial external fixator for closed treatment of type III and IV supracondylar humerus fractures in children. A new surgical technique]. Oper Orthop Traumatol 2014; 26: 75-96; quiz 97.
[22] Kalenderer O, Reisoglu A, Surer L and Agus H. How should one treat iatrogenic ulnar injury after closed reduction and percutaneous pinning of paediatric supracondylar humeral fractures? Injury 2008; 39: 463-466.
[23] Babal JC, Mehlman CT and Klein G. Nerve injuries associated with pediatric supracondylar humeral fractures: a meta-analysis. J Pediatr Orthop 2010; 30: 253-263.
[24] Zhao JG, Wang J and Zhang P. Is lateral pin fixation for displaced supracondylar fractures of the humerus better than crossed pins in children? Clin Orthop Relat Res 2013; 471: 2942-2953.
[25] Brauer CA, Lee BM, Bae DS, Waters PM and Kocher MS. A systematic review of medial and lateral entry pinning versus lateral entry pinning for supracondylar fractures of the humerus. J Pediatr Orthop 2007; 27: 181-186.