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Can a linear external fixator stand as a surgical alternative to open reduction in treating a high-grade supracondylar humerus fracture?

Barak Rinat[1], Eytan Dujovny[1], Noam Bor[1,2], Nimrod Rozen[1,2] and Guy Rubin[1,2]

Abstract

Objective: High-grade pediatric supracondylar humerus fractures are commonly treated with closed reduction and internal fixation with percutaneous pinning. When this fails, open reduction followed by internal fixation is the widely accepted procedure of choice. Use of a lateral external fixator was recently described as an optional procedure, but evidence is scarce.
Methods: We investigated the outcomes of upper limbs treated by either open reduction with internal fixation or closed reduction and external fixation.
Results: Twenty-one patients completed the long-term follow-up; 11 underwent open reduction, and 10 underwent external fixation. Most patients in both groups reported excellent satisfaction. In both groups, the modified Disabilities of the Arm, Shoulder, and Hand score was extremely low and the average elbow range of motion was almost identical. Radiographic analysis consisting of Baumann's angle and the carrying angle revealed no statistical difference between the two groups.
Discussion: Optional treatment using a linear external fixator for complex nonreducible supracondylar humerus fractures yielded acceptable clinical and radiographic results, as with open reduction. Our sample size was small, but the promising results may assist in the implementation of an alternative surgical procedure, especially in more complicated cases involving flexion-type fractures or severe soft tissue damage and swelling.

Keywords

Humerus, external fixation, supracondylar fracture, DASH score, nonreducible, open reduction

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[1]Orthopedic Department, Emek Medical Center, Afula, Israel
[2]Faculty of Medicine, Technion, Haifa, Israel

Corresponding author:
Guy Rubin, Orthopedic Department, Emek Medical Center, Rabin Street, Afula 18101, Israel.
Email: guytair@bezeqint.net

Introduction

Supracondylar humerus fractures (SHFs) are among the most common fractures in the pediatric population, especially in preschool and school-aged children aged 4 to 8 years.[1] SHFs are also the most common fracture treated surgically.[2]

The etiology of SHFs commonly involves low- to moderate-energy trauma, ranging from a minor fall in toddlers to playground injuries in older children.[3,4] Mechanically, most SHFs are believed to occur as a result of hyperextension of the elbow during a fall on an outstretched hand with the olecranon acting as a "hammer" knocking on the olecranon fossa at the posterior aspect of the distal humerus, where fracture propagation begins through the weakest part of the distal humerus.[5] SHFs are roughly divided into two directional types, namely extension and flexion, with the latter constituting only about 1% to 2% of SHFs and showing a predominance for older patients.[6] A comprehensive classification was suggested by Gartland[8] in 1959 and, with minor modifications, currently serves as the primary guideline for treatment. The Gartland classification further divides extension-type fractures into three distinct types (1, 2, and 3, with growing displacement and periosteal damage, respectively) while retaining flexion-type fractures as a lone entity.[7,8] Later, a fourth (multidirectional) fracture type was recognized, characterized by an intraoperative unstable fracture pattern,[9] and type 2 was further divided to subtypes A and B depending whether rotation was present.[10]

Treatment options are derived from the severity of the soft tissue damage and the type of fracture according to the modified Gartland classification.[11] Simple Gartland type 1 fractures are commonly treated conservatively with a long posterior or circular cast. Type 2 fractures can be treated conservatively or surgically by closed reduction and percutaneous pinning (CRPP) with several, usually two or three, Kirschner wires (K-wires). Type 3 fractures, along with type 4 fractures, are the core issue of the present article and are treated surgically with either CRPP or open reduction followed by percutaneous pinning.[12–17] An important group of patients, not part of our study cohort, are those who are suspected to have neurologic or vascular compromise and may need open reduction with or without extensive exploration.[13,18,19]

Technically, a wide consensus exists regarding the need for "near to anatomic" reduction following a severely displaced SHF. Reduction criteria include a Baumann's angle of $>10^\circ$, intact medial and lateral columns on oblique views, and an anterior humeral line passing through the capitellum on the lateral view.[5] Although anatomically speaking, SHFs are extra-articular, rotational, sagittal, or coronal, malalignment can eventually cause significant morbidities with a decreased range of motion in the elbow, late neurologic deficits, or an aberrant physical appearance.

Several options have been described for the surgical technique required to achieve suitable reduction and fixation for type 3 and 4 fractures. Primarily, CRPP is the preferable method because it causes no major soft tissue damage.[17] Once closed reduction has failed and the fracture is either unstable or malreduced, open reduction with internal fixation (ORIF) is usually performed followed by K-wire fixation in the fashion mentioned earlier. The surgical approach can vary between a posterolateral and an anterior approach.[20,21] An alternative technique, which is the main focus of the current work, involves the use of an external fixator with internal fixation (Ex-Fix) for the reduction and fixation of failed closed reduction.

In 2004, Gris et al.[22] showed good results using an elbow-spanning external fixator. Later, in 2008, Slongo et al.[23] described an even less extensive approach using a lateral linear external fixator on the humerus alone. This group reported very satisfying results, but their approach has been scarcely described since.[24]

The main goal of our study was to further evaluate the possible indications for the use of external fixation using the method described by Slongo et al.[23] and assess its clinical outcomes. We compared two groups of pediatric patients who underwent operations in our department from 2010 to 2016. All patients had sustained elbow trauma and were diagnosed with displaced SHFs graded as Gartland 3 or 4, either flexion or extension types, and a few severely comminuted. All patients underwent failed closed reduction prior to the second surgery, which was either open reduction and percutaneous pinning or external fixation.

Patients and methods

Study design and data source

We conducted a retrospective study of healthy pediatric patients admitted to our medical institution from 2010 to 2016. All patients underwent operations in our Pediatric Orthopedic Unit after being diagnosed with a high-grade supracondylar fracture, Gartland stage 3 or 4. All patients underwent an unsuccessful closed reduction attempt under general anesthesia and fluoroscopy in the operating room. After the failed closed reduction, which presented with significant fracture instability, each patient was treated according to the surgeon's personal preference by either open reduction using a lateral approach or fixation using a lateral external fixator according to the method described by Slongo et al.[23] The method described by Slongo et al.[23] involved insertion of two lateral Schanz pins perpendicular to the humerus (one to the shaft and a second to the capitellum) and an additional lateral-radial–sided K-wire, either directed retrograde or antegrade and running obliquely between the two fracture fragments through the olecranon fossa, thus aiding in additional rotational stability. All patients were fitted with a posterior long splint in the operating room. After surgery, the patients remained in the hospital for a few days for routine medical supervision with close neurovascular follow-up, pain control, and prophylactic antibiotic treatment.

After discharge, the patients were summoned for further follow-up in our Outpatient Trauma Clinic. According to the chosen surgical method, either the external fixator or K-wire was removed in the clinic after 5 to 6 weeks along with the splints. The procedure for both methods did not require analgesics or anesthesia. Full free motion was advised with no official referral to physiotherapy. All patients visited the Clinic at least three times in the first 6 weeks and then once every 2 to 3 months until at least 1 year postoperatively. On their last visit, the patients were thoroughly interviewed, along with their parents, if needed. We collected data concerning their general medical history, demographic information, and details of any relevant trauma. They were interviewed concerning everyday functioning, possible hardships, pain, and physical appearance related to the injury. A modified questionnaire based on the Disabilities of the Arm, Shoulder, and Hand (DASH) questionnaire was administered.[25–27] Physical examination was then performed to assess the range of motion, neurological function, and general physical appearance of the affected limb. Finally, standard radiographs, including lateral and anteroposterior views, were taken along with full bilateral upper limb radiographs. All data were stored in the patient's computerized medical file. The exclusion criteria were an age of >12 years and the presence of an underlying medical condition that could affect musculoskeletal growth and metabolism.

Our measured outcomes were functionally scored as described earlier using the modified DASH (mDASH), functional angles measured during physical examination, and radiographic angles as described in the Introduction section. Measurements were taken by two independent, unrelated orthopedic surgeons. The study was approved by our Institutional Review Board. The parents of the patients provided written informed consent to undergo the procedures and for the medical data to be reported.

Statistical methods

Numerical data were collected using an Excel worksheet (Microsoft Corp., Redmond, WA, USA). Categorical variables are presented as frequency and percentage, and continuous variables are presented as mean ± standard deviation [median, interquartile range].

Associations between the categorical variables and study groups were examined using Fisher's exact test. Continuous variables were assessed using the Wilcoxon two-sample test. A p value of <0.05 was considered statistically significant. All statistical analyses and data management were performed using SAS 9.4 software (SAS Institute, Cary, NC, USA).

Results

In total, 33 pediatric patients (71% male) aged 3 to 12 years (mean, 7.9 years) who underwent operations from 2010 to 2016 for high-grade SHFs were subjected to either open reduction or external fixation procedures following a failed closed reduction. After exclusion due to either lack of appropriate follow-up or the presence of a relevant medical condition, 21 patients were included in the study (Table 1). With respect to the fracture type, nine (43.0%) patients had a Gartland 3 extension-type SHF, six (26.8%) had a Gartland 3 flexion-type SHF, and six (26.8%) had a multidirectional or Gartland 4 SHF. Eleven of the patients underwent open surgical reduction, and 10 underwent closed reduction and external fixation. Left-arm fractures numbered twice as many as right-arm fractures (66.6%). No motor or sensory neurologic deficit in the affected limb was documented in any of the patients. No pin tract infection, skin infection, or any other infection possibly related to the surgical procedure was documented. No iatrogenic bony injury possibly related to the insertion of Schanz pins or K-wires was documented in either group. Satisfaction was described as excellent by 16 (76.2%) patients and fair by the rest. The mean elbow flexion was measured as 135°, with eight patients at <140°. An extension angle of 0° was measured in 17 (80%) patients, 3 (14%) of whom had hyperextension of the elbow while 1 lacked full extension. The mean mDASH score was 0.96, with four patients graded at >0. The post-surgical anterior humeral line was measured in the normal alignment in 16 (76.2%) patients, and the remaining patients had extension alignment. The average carrying angle was 7.4° in the injured limb and 9.7° in the healthy limb. The average Baumann's angle was 75.6° in the injured limb and 72.0° in the healthy limb.

We further analyzed the associations between the two groups (Table 2). The mean age at surgery was 8.9 years in the Ex-Fix group and 7.0 years in the ORIF group ($p = 0.22$). Two (20.0%) patients in the Ex-Fix group and five (45.5%) in the ORIF group had right-hand fractures with no statistical difference. The mDASH score was 1.67 in the Ex-Fix group and 0.17 in the ORIF group with no statistical difference. General satisfaction was not statistically different between the two groups; seven (70.0%) patients in the

Table 1. Distribution of study sample including demographic, clinical, and radiographic data.

Age at surgery, years	7.88 ± 2.89 [8.6, 6–10]
Male sex	15 (71.43)
Clinical data	
Right side	7 (33.33)
Left side	14 (66.67)
Nerve deficit	0 (0.00)
Excellent satisfaction	16 (76.19)
Fair satisfaction	5 (23.81)
Unsatisfied	0 (0.00)
Degree of flexion	135.24 ± 8.73 [140, 130–140]
Flexion of <140°	6 (28.57)
Degree of extension	−0.95 ± 4.64 [0, 0–0]
Extension of 0°	17 (80.95)
Extension of <0°	3 (14.29)
Extension of >0°	1 (4.76)
mDASH score	0.96 ± 2.52 [0, 0–0]
mDASH score of >0	4 (19.05)
Imaging Data	
Extension-type fracture	9 (42.86)
Flexion-type fracture	6 (28.57)
Multidirectional fracture	6 (28.57)
Anterior humeral line, normal	16 (76.19)
Anterior humeral line, extension	5 (23.81)
Carrying angle, injured side	7.38 ± 9.13 [6, 3–11]
Carrying angle, healthy side	9.76 ± 5.19 [10, 7–12]
Baumann's angle, injured side	75.76 ± 4.55 [75, 73–80]
Baumann's angle, healthy side	72.00 ± 6.56 [72, 69–75]

Categorical variables are presented as frequency and percentage. Continuous variables are presented as mean ± standard deviation [median, interquartile range] mDASH, modified Disabilities of the Arm, Shoulder, and Hand.

Ex-Fix group and nine (82.0%) in the ORIF group described their satisfaction as excellent. The general appearance of the surgical site was also categorically estimated and documented. Five (45%) patients in the ORIF group had a hypertrophic scar, but all patients in the Ex-Fix group had only minor surgical scars and no hypertrophic scars. One patient in the ORIF group with a hypertrophic scar also sustained a possible minor extensor muscle herniation in proximity to the hand extensor-mass origin.

Elbow flexion was slightly greater in the ORIF than Ex-Fix group (138° vs. 132°, respectively), and elbow extension slightly higher in the Ex-Fix than ORIF group (−2° vs. 0°, respectively), but neither was statistically different. The carrying angle in the ORIF group was statistically higher than that in the Ex-Fix group (11° vs. 3.4°, respectively; $p = 0.03$) (Figure 1). The carrying angle in the healthy limb was not significantly different between the two groups. Comparison of Baumann's angle between the injured elbows of both groups as well as between the healthy elbows of both groups showed no statistical difference. Two patients (one in each group)

Table 2. Comparison of demographic, clinical, and radiographic factors between the study groups.

	Surgery type		
	Open n = 11	Ex-Fix n = 10	p value
Age at surgery, years	6.98 ± 3.20 [7.7, 3.7–10.4]	8.86 ± 2.27 [9.1, 7–10]	0.22
Male sex	7 (63.64)	8 (80.00)	0.64
Clinical data			
Right side	5 (45.45)	2 (20.00)	0.36
Nerve deficit	0 (0.00)	0 (0.00)	–
Excellent satisfaction	9 (81.92)	7 (70.00)	0.64
Degree of flexion	138.18 ± 4.05[140, 140–140]	132 ± 11.35[140, 120–140]	0.20
Flexion of <140°	2 (18.18)	4 (40.00)	0.36
Degree of extension	0 ± 4.47 [0, 0–0]	−2 ± 4.83 [0, 0–0]	0.33
Extension of 0°	9 (81.82)	8 (80.00)	>0.99
Extension of <0°	1 (9.09)	2 (2.00)	
Extension of >0°	1 (9.09)	0 (.00)	
mDASH score	1.67 ± 3.36 [0, 0–1.7]	0.17 ± 0.54 [0, 0–0]	0.30
mDASH score of >0	8 (72.73)	9 (90.00)	0.59
Imaging Data			
Extension-type fracture	5 (45.45)	4 (40.00)	>0.99
Flexion-type fracture	3 (27.27)	3 (30.00)	
Multidirectional fracture	3 (27.27)	3 (30.00)	
Carrying angle, injured side	11 ± 7.39 [8, 5–15]	3.4 ± 9.55 [3, 3–9]	0.03
Carrying angle, healthy side	11.45 ± 6.01 [12, 7–16]	7.90 ± 3.51 [9, 7–10]	0.12
Baumann's angle, injured side	74.91 ± 4.5 [74, 70–78]	76.7 ± 4.64 [77.5, 73–80]	0.35
Baumann's angle, healthy side	68.64 ± 6.25 [69, 66–73]	75.70 ± 4.81 [75, 72–80]	0.012
Anterior humeral line in extension	1 (9.09)	4 (40.00)	0.15

Categorical variables are presented as frequency and percentage. Continuous variables are presented as mean ± standard deviation [median, interquartile range].
mDASH, modified Disabilities of the Arm, Shoulder, and Hand; Ex-Fix, external fixator with internal fixation.

had a radiographic bony bridge above the lateral epicondyle.

Discussion

In this retrospective study, we examined the clinical and radiographic results of two distinct surgical treatments for severely displaced pediatric SHFs, both of which were performed following failed attempts with closed reduction. Other than the carrying angle in the ORIF group, which was slightly larger toward valgus alignment, no significant clinical or radiographic differences were noted between the two groups, and the range of motion and radiographically measured angles were acceptable.[28–30] Clinical outcomes, including general satisfaction, range of motion, neurovascular intactness, and functional score, did not differ between the two groups and were within the accepted normal ranges for the pediatric population. Hypertrophic scars were only found in the ORIF group.

There was also no statistical difference in the patients' age or side of the injured limb, although the mean age was slightly higher in the Ex-Fix group. A possible explanation for the apparent age difference could be a decline in the fracture stability with growing age along with increasing comminution, features that might benefit external fixation.

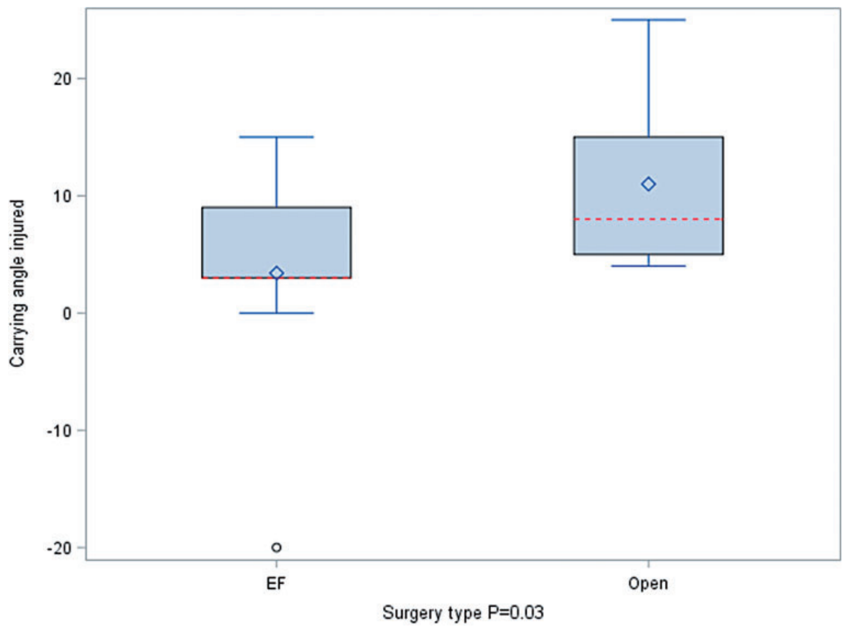

Figure 1. Box plot of distribution of the carrying angle (injured limb) by type of surgery. Doted red line = median; diamond = average; blue box limits = interquartile range.

Open reduction with internal fixation by guide-wires remains the mainstay of treatment after failed closed reduction of high-grade SHFs.[5,12–16] This study aimed to compare the open reduction method with a significantly less invasive technique using closed reduction and external fixation. The study results reflected a lack of significant differences between the two methods with respect to movement and function, with apparently less scarring and soft tissue trauma in the external fixator technique. In our view, both the clinical and radiographic outcomes correspond with earlier data that demonstrated satisfactory range of motion in almost all patients who underwent closed reduction and external fixation, as well as excellent cosmetic results[23,24] and no postsurgical neurovascular damage. These studies, along with ours, support the optional use of the external fixator technique.

Nonetheless, our study had several limitations. Our experience in practicing the external fixator technique is only in its infancy; thus, the surgical results may improve as we become more specialized in the surgical technique and patient selection. Our cohort was based upon pediatric patients who underwent operations in our institution from 2010 to 2016, and all underwent close follow-up for at least 1 year postoperatively. Unfortunately, long-term follow-up has its downside. Some of the patients were reluctant or unable to complete the medical follow-up for various objective reasons, such as living far from our institution, a low economic status making clinic visits a true burden, or lack of interest in further long-term follow-up, perhaps because of their satisfactory everyday function and appearance.

Although we believe that our results are very promising, the sample size remains the prime limitation. This study included all eligible operations in our medical center, and no *a priori* sample size was calculated.

Based on the study results, we calculated the statistical power of the non-inferiority assumption for each of the four primary endpoints of the study (flexion, extension, carrying, and Baumann's angles) using a margin of 5 (the endpoint standard deviations were used accordingly), with a one-sided α of 5% and with a known sample size of 21 patients (11 who underwent open surgery and 10 who underwent the external fixator technique). The statistical power of the flexion, extension, carrying, and Baumann's angles was 34.3%, 76.1%, 35.5%, and 77.5%, respectively. Acknowledging the statistical limitations, we can assume that at least for extension and Baumann's angle, the sample size was nearly adequate.

While not underestimating the limitations of our research, especially concerning its retrospective design and small sample size, we strongly believe that practicing an alternative method in accordance with the "classic" evidence-based method of open reduction can provide the operating surgeon with further flexibility in treatment options. Furthermore, in our view, special circumstances such as flexion-type fractures, extreme limb swelling, soft tissue damage, or susceptibility to scarring might present external fixation as the leading option. We have great confidence that a large-scale study can yield similar results and may help more surgeons to accept the linear external fixation technique as an "over-the-counter" option for the treatment of such fractures.

Author's Note

Barak Rinat and Eytan Dujovny are now affiliated with Orthopedic Department, Emek Medical Center, Afula, Israel.

Declaration of conflicting interest

The authors declare that there is no conflict of interest.

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