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Original article

Surgical strategies in pediatric supracondylar humeral fractures: our experience

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Abstract. *Background and aim:* Supracondylar humeral fractures are the most common skeletal injury of childhood elbow. Treatment option for Gartland type II-III-IV fractures is based on closed reduction and percutaneous pinning (CRPP) fixation using Kirshner wires. Seldom open reduction is needed. Literature described different method of CRPP. The aim of the study is to report our experience in the surgical management of supracondylar humeral fractures comparing it with the literature, in order to identify useful information for a correct and better approach to reduce complications and improve clinical outcomes. *Methods:* 148 patients with a mean age of 5.72 ± 2.52 years and with Gartland type II-III-IV humeral supracondylar fractures were treated with CRPP at our Orthopedic Pediatric Unit. They were divided into three groups according to surgical technique. Group A was represented by patients treated with cross pinning (1 medial and 1 lateral pin), Group B represented by 2 lateral pins while Group C represented by 2 lateral and one medial pin. Evaluation criteria are based on Mayo Elbow Performance Index (MEPI); Bauman's and Carrying Angle and Flynn's criteria. Data were recorded at the following times: T0 (before surgical procedure); T1 (one-month post-surgery); T2 (six months post-surgery). *Results:* The three surgical techniques showed comparable results according to MEPI, Bauman's angle, Carrying's angle and Flynn's criteria from T0 to T1. There is an improvement for all Groups. Group C reported the best MEPI outcome at T2. However, 2 patients in this group did not show excellent results according to Flynn's criteria. *Conclusions*: There is no single and superior treatment for displaced humeral supracondylar fractures and that each fracture has its own personality. (www.actabiomedica.it)

Key words: supracondylar humeral fractures, elbow, Gartland classification, pediatric, closed reduction with percutaneous pinning, K-wires

Introduction

Supracondylar humeral fractures are the most common skeletal injury of the elbow in childhood, with a peak incidence between 5 and 7 years in both sexes and a prevalence of male sex and left side. In 98% of cases, this type of fracture is caused by an accidental trauma as a fall from a height. or otherwise during sport activities. This type of fracture is rare in children under 15 months, in these cases, the hypothesis of maltreatment must be considered. The most common traumatic mechanism is a fall with the wrist and elbow in extension and forearm in pronation. In this situation the elbow is in a condition of "joint block"; the discharge of forces is exerted on the humeral blade, causing its fracture. More rarely, only in 2% of cases,

the traumatic mechanism is due to a fall with the elbow in flexion. At clinical examination the elbow is swollen, sometimes with an alteration of the anatomical profile, ecchymosis at the antecubital fossa (called Kirmisson's sign) and joint functional inability (1). The Gartland classification of supracondylar fractures of the humerus is based on the degree and direction of displacement and the presence of intact cortex (2). The clinical examination is essential to evaluate the presence or absence of the radial pulse, the capillary refill time, the turgor of the fingertip, the functionality of the median, anterior interosseous, radial and ulnar nerves. Sensor and motor examination is not easy to perform in children; it is useful to inform parents that neurological injuries are often a direct consequence of the trauma. A more accurate evaluation will be possible only after the stabilization and immobilization of the fracture, in absence of pain and post-trauma anxiety.

The radiological evaluation is based on the two standard antero-posterior and lateral views.

Treatment options include immobilization in brachometacarpal cast braces for 4-6 weeks (times variable according to the child's age) for Gartland type I compound fractures and closed reduction and fixation with percutaneous pinning (CRPP) using Kirshner wires (K-wires) in case of displaced Gartland type II-III-IV fractures. Seldom open reduction is needed, as in other bone segments (3-6).

Complications of supracondylar fractures can be divided into two groups: immediate and late. The immediate complications are vascular lesions (10-20%) (7-8) represented by lesions of the brachial artery, the ischemic hand, the perfused hand without radial pulse (Pink Pulseless Hand) (7-12%) (9-10), neurological lesions (6.5-19%) (11), compartment syndrome (less than 7% of cases). Late complications are cubitus varus (26.1%) (12), joint stiffness and vicious consolidations, necrosis of the trochlea (13).

The aim of the study is to report our experience in the surgical management of supracondylar humeral fractures comparing it with the literature, in order to identify useful information for a correct and better approach, as much as possible based on evidence, in order to reduce complications and improve clinical outcomes.

Material and method

This is a retrospective, monocenter study, performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. Ethical review and approval were waived for this study. All the patients' parents involved in the study gave their informed consent prior to their inclusion in the study. Patients who suffered of supracondylar fractures of the humerus and were treated surgically at the Pediatric Orthopedics and Traumatology Unit of the "Giovanni XXIII" Pediatric Hospital in Bari between January 2018 and December 2021were enrolled in this study.

The inclusion criteria were: pediatric patients (age less than 13 years old), Gartland type II-IV, absence of other fractures and trauma, absence of congenital and/or genetic pathologies, active infectious, neuromuscular and underlying vascular diseases.

The exclusion criteria were: open fracture and patients who were not able to understand and complete the procedure due to cognitive dysfunction or language barrier.

Between January 2018 and December 2021, one hundred and forty-eight patients with Gartland type II-III-IV humeral supracondylar fractures were evaluated for eligibility for the present study and divided into three groups according to surgical technique. All patients were treated under general anesthesia, after appropriate preoperative planning, in supine decubitus with reduction and percutaneous pinning with Kirschner wires with a diameter from 1.4 to 2 mm (depending on the age of the patient) in numbers ranging from 2 to 3 and positioned according to the type of fracture and degree of displacement, with an increase in the number of wires with increasing the degree of displacement of the fracture as Blount's technique (14).

Group A was represented by patients treated with cross pinning (1 medial and 1 lateral pin), Group B represented by 2 lateral pins while Group C represented by 2 lateral and one medial pin. Patients underwent standard radiographs in both anteroposterior and lateral views both pre and post-operative.

Figures 1a, 1b and figures 2a, 2b show a preoperative and postoperative x-rays of humeral supracondylar fracture of group C. Figure 3a, 3b and figure 4a, 4b

Figure 1a, 1b. Preoperative radiograph in frontal and lateral view of right humeral supracondylar fracture.

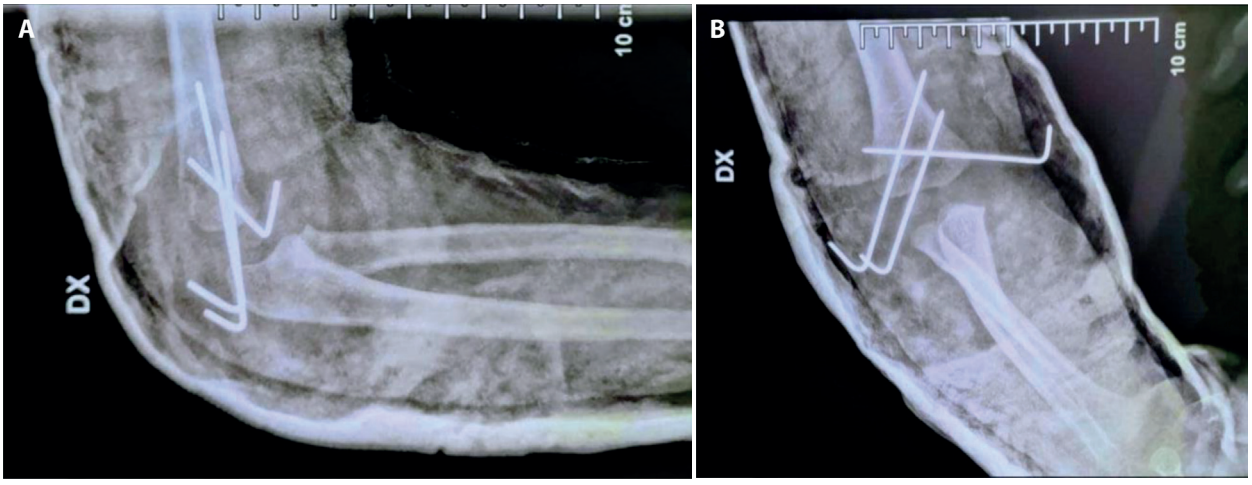

Figure 2a, 2b. Postoperative radiograph in frontal and lateral view of right humeral supracondylar fracture treated with 2 diverging radial and 1 ulnar K-wires

show a preoperative and postoperative x-rays of humeral supracondylar fracture of group A

After surgery, a brachiometacarpal plaster immobilization was applied for 30 days and then removed after appropriate radiographic control. The Kirshner wires were removed as day service procedure without any sedation. The patients then underwent a rehabilitation program after regular physiatric consultation.

For each patient, the following data were recorded: age; sex; body mass index (BMI) according pediatric percentile ranges (15); side of surgery; place of injury; time to surgery; hospital stay (day); Gartland

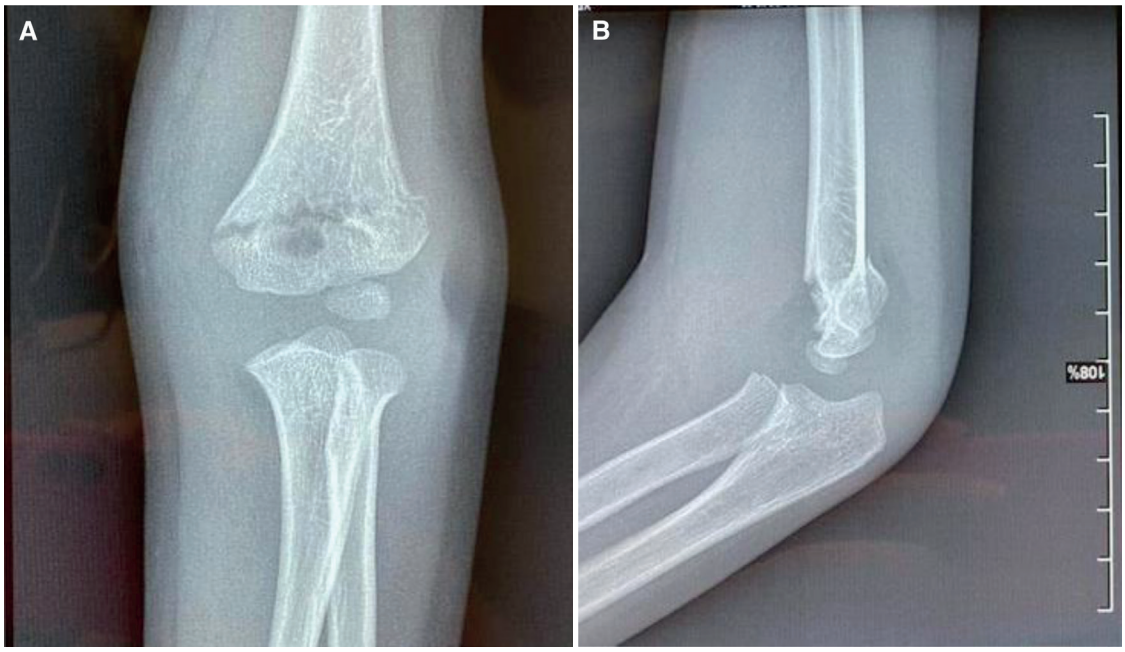

Figure 3. Preoperative radiograph in frontal and lateral view of left humeral supracondylar fracture

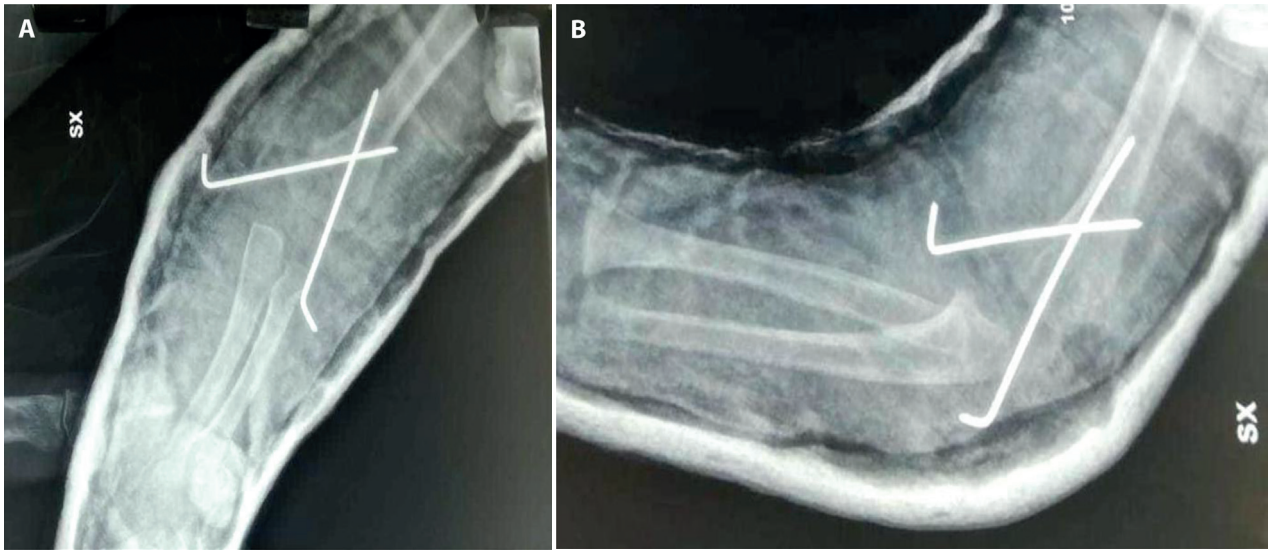

Figure 4. Postoperative radiograph in frontal and lateral view of left humeral supracondylar fracture treated with 2 crossed K-wires.

type; surgical technique; Mayo Elbow Performance Index (MEPI) (16); Bauman's and Carrying Angle (17); Flynn's criteria (18).

Mayo Elbow Performance Index (MEPI) is a specific elbow evaluation scale which describes painful symptoms, function and stability of the elbow and range of motion, adapting the items relating to the use of the operated limb in daily activities at the age of small patients (recreational, sports and school activities).

Bauman's angle is measured on the anteroposterior projection of the radiograph and is defined by a

line passing through the longitudinal axis of the humerus and a line passing below the capitulum humeri after the reduction maneuver and which has a normal value of about 75 °; an increase of 5 or more degrees indicates a varus deformity, a decrease of more than 5 ° describes a valgus deformity.

Carrying Angle evaluates varus-valgus angulation of the arm with elbow fully extended and forearm completely supinated. This angle is measured by the line runs along the middle axis of the arm and the line that runs along the middle axis of forearm. There is significant difference based on age. At the age of 0-4 years the value is about 15º and 17.8º in adults. The angle increasing indicates a valgus deformity and reducing the varus deformity.

The Flynn's criteria are used to grade functional and cosmetic outcomes at the last follow-up.

Data were recorded at the following times: T0 (before the surgical procedure); T1 (one-month post-surgery); T2 (six months post-surgery).

A retrospected clinical study was conducted. Data were collected and analyzed using SPSS (v 23; IBM® Inc., Armonk, NY, USA). Descriptive statistics were calculated for the overall sample and for follow-up. Categorical variables were presented as numbers or percentages. Continuous variables were presented as mean and standard deviation. Due to the non-homogeneous distribution of the values using the Kolmogorov–Smirnov test ($P > 0.05$), non-parametric tests were considered. To compare the average values between the groups at the same times, the Kruskall Wallis test or Fischer's test were used, when appropriate. To compare the value within the same group at different times, the Related-Samples Friedman's test Two-Way Analysis of Variance were used. To demonstrate the correlation between the outcomes and variables, a multiple regression model was then fitted. To demonstrate the correlation between the surgical procedure and the fracture pattern according to Gartland type, the Spearman's Rho correlation was used. For all the tests, a p-value of less than 0.05 was considered to be statistically significant.

The data presented in this study are available on request from the corresponding author.

Results

We retrospective enrolled a hundred and forty-eight patients with Gartland type II-IV humerus supracondylar fractures surgically treated at our Department. Preoperative features of the subjects were described in Table 1.

None of the patients experienced any skin complications due to the treatment or plaster. None of patients need for revision surgery due to infection and mechanical relaxation in the early period. Neither intraoperative nor postoperative complication was recorded.

The MEPI scores, Bauman, Carrying angle and the Flynn's criteria before and after surgery were noted for each time in Table 2. No difference was shown

Table 1. Pre-operative main data of the study (BMI=body mass index).

Preoperative features	**mean ± standard deviation or number and percentage**
Age (year)	5.72 ± 2.52
Gender (female)	77 (52.03%)
BMI	
Underweight	26 (17.6%)
Healthy weight	110 (74.3%)
Overweight	12 (8.1%)
Side (left)	69 (46.6%)
Place of injury	
home	20 (40%)
outdoor	16 (32%)
Time to surgery (hour)	10.23 ± 5.55
Hospital stay (day)	1.90 ± 0.51
Gartland type	
Type II	68 (45.9%)
Type III	42 (28.4%)
Type IV	38 (25.7%)
Surgical technique	
Cross pinning (1 medial and 1 lateral pin)	22 (14.9%)
2 lateral pins	30 (20.3%)
2 lateral and one medial pin	96 (64.9%)

Table 2. Differences of outcomes studied between groups (MEPI= Mayo Elbow Performance Index).

		Group A	Group B	Group C	p-Value
MEPI score	T0	12.75 ± 2.97	12.24 ± 3.71	12.80 ± 3.26	0.82
	T1	54.11 ± 9.39	52.73 ± 7.77	53.77 ± 9.32	0.62
	T2	87.58 ± 8.09	86.32 ± 8.70	91.83 ± 8.06	**0.01**
Bauman's angle	T1	74.68 ± 1.67	74.34 ± 1.76	74.79 ± 1.92	0.31
	T2	74.69 ± 2.34	74.38 ± 1.88	75.50 ± 2.19	0.05
Carrying angle	T1	14.58 ± 0.92	15.16 ± 1.20	14.98 ± 1.01	0.07
	T2	15.18 ± 0.87	14.98 ± 0.82	15.13 ± 1.13	0.87
Flynn's criteria	T2	Excellent (100%)	Excellent (100%)	Excellent (94%)	0.41

Table 3. Differences of outcomes studied within groups (MEPI= Mayo Elbow Performance Index).

		Pre-operative vs. one month	One month vs. six months	Related-Samples
Group A	MEPI score	**0.01**	**0.01**	**0.01**
	Bauman's angle	-	0.81	-
	Carrying angle	-	0.05	-
Group B	MEPI score	**0.01**	**0.01**	**0.01**
	Bauman's angle	-	0.67	-
	Carrying angle	-	0.13	-
Group C	MEPI score	**0.01**	**0.01**	**0.01**
	Bauman's angle	-	0.05	-
	Carrying angle	-	0.40	-

pre-operatively using Kruskall Wallis test. The T2 Group 3 MEPI score recorded was higher than the others (91.83 ± 8.06, P=0.01). Conversely, Group 3 Flynn's criteria excellent rate at last follow-up was lower than the others although not statistically significance using Fischer's test.

No differences were demonstrated between groups according to the angles.

Table 3 showed outcome differences within the groups using the Related-Samples Friedman's test Two-Way Analysis of Variance and Wilcoxon test. We demonstrated MEPI score improved from preoperative to last follow-up for each group. Bauman's and Carrying angle did not differ from T1 to T2 for each group denoting proper reduction of the fracture with surgical treatment.

The multiple linear regression models showed MEPI score were positively influenced by surgical technique, group 3 had better values according to the table 2. The studied angles were not influenced by demographic features and type of surgery. Moreover, the Carrying angle was positive influenced by Gartland type fracture, complex fractures had higher angle (table 4).

A Rho Spearman's correlation demonstrated a statistical difference between the different surgical approaches and fracture type. More complex fractures according to Gartland classification required the use of multiple pins (Spearman's Rank Correlation Coefficient = 0.23; p = 0.01).

Discussion

The most used osteosynthesis techniques in literature are those with two diverging lateral wires or with two crossed wires (one lateral and one medial).

Table 4. Multiple linear regression models for outcomes.

	MEPI				Bauman's angle				Carrying angle			
	B	**95% CI**		**p-Value**	**B**	**95% CI**		**p-Value**	**B**	**95% CI**		**p-Value**
Intercept	-14.34			**0.01**	73.96			**0.01**	14.01			**0.01**
Group	1.02	0.04	1.99	**0.01**	0.34	-0.12	0.23	0.64	0.05	-0.12	0.23	0.52
Age	-0.36	-0,69	-0,05	**0.01**	-0.03	-0.15	0.07	-0.24	-0.02	-0.08	0.32	0.40
Sex (female)	-1.78	-3.28	-0.28	**0.01**	-0.06	-0,01	-0.57	0.80	-0.16	-0,10	-0.43	0.24
Left knee	-0.25	-1.63	1.13	0.73	-0,16	-0,63	0,31	0,51	0.09	-0,15	0,34	0,43
BMI	–0.54	-2.09	1.01	0.49	-0,21	-0,75	0,31	0,42	-0,10	-0,37	0,17	0,45
Time to surgery	–0.04	-0.17	0.09	0.51	0.06	-0.04	0.05	0,78	0.02	0.01	0.05	**0,06**
Hospital stay	–3.17	-4.60	-1.74	0.55	-0,01	-0.36	0.62	0.61	-0,01	-0.27	0.23	0.90
Gartland type	-0.47	-1.37	0.43	0.31	-0,04	-0,35	0,27	0,79	0.19	0.03	0.35	**0.02**
Time	38.70	37.87	39.53	**0.01**	0.47	0.04	0.94	0.24	0.15	-0.09	0.39	0.22

To date, none of the methods seems to be absolutely more reliable. The two key points in the choice of the construct are the stability of the synthesis and the risk of nerve injury, especially of the ulnar nerve.

Related to the stability of the synthesis, biomechanical studies have shown that the two techniques show comparable results while it is inferior only in case of using parallel or converging lateral threads (19).

In unstable fractures treated with lateral Kirschner wires, the biomechanical seal can be increased with the addition of a third wire (the most frequent treatment in our series), to counteract rotational stress, as demonstrated with the Spearman's correlation.

The use of crossed wires (one medial and one lateral) is burdened by a greater risk of injury to the ulnar nerve (6% against 0,53% obtained with all-lateral pinning fixation) (20); it can be caused both by the transfixion of the nerve by the Kirschner wire and by the compression in its course by secondary scarring fibrotic phenomena (21). We would like to underline that in our series there are no episodes of iatrogenic nerve damage in any patients.

The use of a mini-incision at the level of the epitrochlea may be a valuable aid in order to reduce the risk of this complication, especially in elbows with marked swelling (22). In fact incidence of ulnar nerve injury is reduced in case of insertion of the medial wire avoiding hyperflexion of the elbow or using a mini access, especially in cases of markedly swollen elbow or patients with elevated BMI or performing reduction and osteosynthesis in prone position.

Therefore, is recommended to adapt the treatment strategy not only to the characteristics of the fracture but also to the surgeon's experience with the different osteosynthesis techniques.

In the Gartland Type III fracture in patients without evident vascular and neurological compromises, the analysis of the literature does not show significant differences in relation to surgical timing, within or 6-8 hours after of trauma, in terms of postoperative complications such as infections, neurological lesions or compartment syndrome and postoperative clinical outcomes. For this reason, some authors advise against acute nocturnal interventions (23). Our time to surgery is average 10.23 hours after trauma.

The fracture characteristics (degree of displacement), the presence or absence of neurovascular lesions, the time of access of the patient to the emergency room as well as the experience of the surgical and anesthetic team are the factors that influence the choice of the timing of treatment of a Gartland type III supracondylar fracture (24).

Open reduction should only be considered in cases where correct alignment of the skeletal abutments is not achieved after attempts of bloodless external reduction or when there are vascular or neurological lesions that require debridement; repeated manipulations, especially in cases of markedly swollen

elbows, can be the cause of neuroapraxia and future joint stiffness (25).

Therefore, the importance of treating these lesions of surgical interest is renewed only in highly specialized centers.

The supine position is the most historically used in the treatment of reduction and osteosynthesis of supracondylar fractures. It is emphasized, as an advantage of the prone position, that the reduction is facilitated by the force of gravity of the dangling forearm which self-reduces the distal fragment displaced posteriorly in the sagittal plane and automatically places the humeral blade, which rests on a support, in position correct in the frontal plane. Some authors also highlighted, among the advantages of the osteosynthesis technique of the supracondylar fracture of the elbow in the prone position, the reduced risk of injury to the ulnar nerve during osteosynthesis with Kirschner wire (26). Venkatadass et all., instead showed in a randomized controlled study that there is no significant difference in the ease of reduction and pinning between supine and prone positions. Grossly displaced fractures with skin puckering are difficult to manipulate in prone position. Supine position was ideal for closed reduction and pinning of all patterns of type III supracondylar fractures (27).

As regards our series, all young patients were treated in supine position also to facilitate anesthetic maneuvers. Our study group consisting of 148 patients, 22 were treated with cross pinning, 30 with lateral pinning and 96 with 2 lateral and 1 medial pins. The three surgical techniques showed comparable results according to MEPI, Bauman's angle, Carrying's angle and Flynn's criteria from T0 to T1. There is an improvement for all surgical techniques in the evaluation scores even at six months compared to the first month follow up. This improvement was statistically significant according to MEPI in group C, patients treated with 2 lateral and 1 medial pins. However, 2 patients in this group did not show excellent results according to Flynn's criteria.

Conclusion

Considering our experience and the most current literature there is no single and superior treatment for displaced humeral supracondylar fractures and that each fracture has its own personality.

It is important the preoperative planning that allows to carry out the most appropriate reduction maneuver and to choose the best position, size and number of wires, in order to have maximum stability of the fracture. Achieving a satisfactory radiographic and functional outcome also reduces the risk of peri- and postoperative complications.

One of the limitations regarding the treatment of these fractures remains the timing of surgery which should be performed as soon as possible to avoid both further displacement that could lead to vascular-nerve complications and significantly swollen elbow thus affecting the correct positioning of the K-wires, with a greater risk of iatrogenic lesion of the ulnar nerve.

We recommend the treatment of these fractures in specialized pediatric orthopedic centers.

Conflict of Interest: Each author declares that he or she has no commercial associations (e.g. consultancies, stock ownership, equity interest, patent/licensing arrangement etc.) that might pose a conflict of interest in connection with the submitted article.

Ethics Approval and Consent to Participate: This is a retrospective, monocenter study, performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki. Ethical review and approval were waived for this study. All the patients' parents involved in the study gave their informed consent prior to their inclusion in the study.

Author Contributions Statement: GM, GN, DD Have made a substantial contribution to the concept or design of the article; GM, GN, MC, GDC, CS Have made the acquisition, analysis, or interpretation of data for the article; GM, GN, VP, BM Drafted the article or revised it critically for important intellectual content; GM, GN, VP, BM Approved the version to be published; GM, GN, MC Agreed to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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