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Evaluation of Intraoperative Peripheral Nerve Stimulator Assisted Percutaneous Medial Pin Placement for Supracondylar Humerus Fractures in Children

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Abstract: ***Background**: Supracondylar fractures of the humerus are widely regarded as the most common fractures around the elbow in pediatric age group, and account for around 60–70% of all pediatric elbow fractures. Proper management of supracondylar fractures is important as they may lead to undesired catastrophic consequences. The treatment options depend on the fragment displacement degree and the presence of a neurovascular injury. An accepted widely known classification of these fractures is the AO/Gartland system, as modified by Wilkin. **Objective**: To assess the accuracy, feasibility, and reliability of the peripheral nerve stimulator during and after medial pin placement in surgical management of supracondylar fractures in children. **Patients and Methods**: This prospective interventional clinical trial was conducted on 50 children with supracondylar fracture of humerus; in the Orthopedics Department of Suad Kafafi Teaching Hospital, Misr University for Science and Technology, School of Medicine, Cairo, Egypt. All patients were subjected to complete clinical picture and careful clinical examination. All patients needed X-ray films; AP/lateral view. **Results**: Age was distributed as 6.28 ± 2.36 years with minimum of 2 years and maximum of 11 years. Regarding sex distribution, male represents majority with 72% and female with 28%. Median time before surgery was zero with minimum of zero and maximum of 8 days. Intraoperatively, medial epicondyle was palpated in all patients. **Conclusion**: The peripheral nerve stimulation during the percutaneous medial pinning of supracondylar fractures in children is a simple, economical, and easily implemented technique, which is helpful in avoiding iatrogenic injury. It can be applied with the equipment already existing in the operation room, as it is also routinely used by anesthesiologists.***

Keywords: Supracondylar fractures, peripheral nerve stimulator, ulnar nerve injury, Closed reduction and percutaneous pinning, intraoperative peripheral nerve stimulator

1. Introduction

Supracondylar fractures of the humerus are widely regarded as the most common fractures around the elbow in pediatric age group, and account for around 60–70% of all pediatric elbow fractures.[1] Proper management of supracondylar fractures is important as they may lead to undesired catastrophic consequences.[2] The treatment options depend on the fragment displacement degree and the presence of a neurovascular injury.[3] An accepted widely known classification of these fractures is the AO/Gartland system, as modified by Wilkin.[4] Closed reduction and percutaneous pinning (CRPP) comprise the mainstay of surgical management to most of those fractures. Pin configuration should ensure mechanical stability while avoiding iatrogenic nerve injury.[1] Yet, controversy exists with regards to size, number of pins and pin configuration. BOAST guidelines (British Orthopedic Association Standards of Trauma) attempt to standardize assessment and treatment of these injuries.[5]

Biomechanically, the cross Kirschner wire pinning configuration is the strongest, specifically for resisting axial rotation, as tested on both human cadaver models and synthetic bone models.[6] However, the anatomical location of the ulnar nerve is close to the medial pin placement, which presents a risk of iatrogenic nerve injury during medial pinning; the incidence of iatrogenic ulnar nerve injury has been reported to range from 4% to15%.[7] This type of injury is most likely caused by difficulty to identify the location of the ulnar nerve before surgery with anatomical landmarks, because of the significant swelling caused by both the trauma and induced fracture.[8] Another reason for the increased incidence of ulnar nerve injury includes the proximity of the medial pin to the nerve, resulting in direct penetration, kinking or contusion. This has led some authors to advocate closed reduction with only lateral pin fixation despite the biomechanical superiority of cross pin fixation technique.[6]

High rates of ulnar nerve instability have been reported in the normal pediatric population. The age group with the greatest ulnar nerve instability was the middle age group, 6 to 10 years.[9] The clinical relevance of this finding is that instability of the ulnar nerve increases the risk of nerve damage during operative treatment of supracondylar humerus fractures in children. The accuracy of clinical assessment of ulnar nerve location by palpation is uncertain, as it has been shown that instability of the ulnar nerve predicted by palpation is often different than the actual location as determined by intraoperative nerve stimulation or direct visualization.[9,10]

Several strategies have been suggested to avoid ulnar nerve injuries during medial pin placement. These include; placing only lateral pins[11], appropriate control of elbow flexion/extension during pin insertion[12], limited exploration of the ulnar nerve via mini-incision during medial pin insertion,[13] Dorgan's technique[14], and finally intraoperative ultrasound guided pin placement[15] Such strategies have also shown to reduce the incidence of the nerve injury.[11-15] The use of electrical stimulation to test the ulnar nerve continuity before and/or during pin insertion has been described in only three earlier studies.[16]

In conclusion, despite the claimed benefit for the use of peripheral electrical nerve stimulation to identify and protect the ulnar nerve during medial pin placement still further studies are needed not only to confirm its accuracy, feasibility, and outcomes but also to prove its superiority over the conventionally used methods for medial pin placement in cross pinning technique.

Therefore, Research community has a defect in knowledge regarding this novel technique using peripheral nerve stimulator intraoperatively to prevent iatrogenic ulnar nerve injury during percutaneous medial pin placement for supracondylar humerus fractures in children.

Aim of the work

The aim of this work is to assess the accuracy, feasibility, and reliability of the peripheral nerve stimulator during and after medial pin placement in surgical management of supracondylar fractures in children.

2. Patients and Methods

Source of data: The present study involved 50 children who have sustained supracondylar fractures humerus Gartland type II (15 cases), type III (32 cases) and type IV (3 cases) were treated in the orthopedics department of Suad Kafafi Teaching Hospital, Misr University for Science and Technology, School of medicine, Cairo, Egypt between November 2021 to December 2022.

Type of study: A primary data research, prospective interventional clinical trial study.

Ethical issues: This study involves operative procedure, which is invasive. The college ethical committee has granted permission for the study and consent of all the patients was taken before the procedure. Approval number: 0014

Method of data collection: Children with supracondylar fracture of humerus who fulfilled the eligibility criteria were included in the study.

Study population: Study participants were selected in consecutive manner. The study was held on patients ageing from 1-14 years old of both genders suffering from supracondylar humerus fractures presenting at the time of initial visit to emergency ward/outpatient clinic after trauma.

Inclusion eligibility criteria: Children (1-14 years) suffering from displaced, unstable supracondylar humerus fracture. (Gartland type 2, 3, 4, Medial comminution, flexion type supracondylar fractures, and Reverse oblique type).

Exclusion eligibility criteria: Exclusion criteria are neurological disorders, Bone dysplasia, History of prior fractures around the injured elbow, History of prior elbow septic arthritis/infection, Supracondylar humerus fractures associated with congenital or acquired musculoskeletal disorders, Ulnar nerve injury due to initial trauma, Open fractures requiring debridement, Supracondylar humerus fractures failed initial closed reduction and open reduction is required. The preoperative parameters that were recorded included the age, sex of the patient, Side, fracture pattern, preoperative nerve deficit and medical history. Plain radiographs were obtained on admission, and all fractures were categorized according to Wilkins Modification of Gartland's classification. This study included fifty patients with age range from 2 to 11 years with average age 6 years. There were 36 males and 14 females. Female represented 28% of patients. (Figure 1)

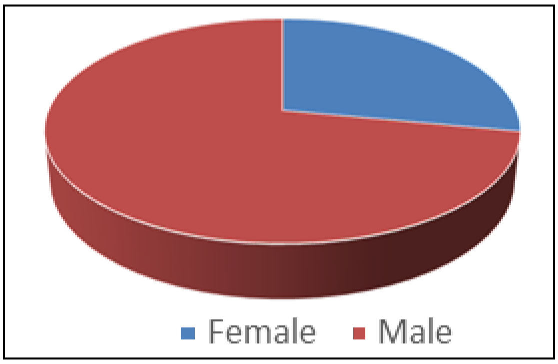

Figure (1): Pie chart showing distribution of patients according to gender.

Time to surgery ranged from 0 to 8 days with 62% of patients underwent surgery on the same day, 24% were operated after one day and 14% were operated after 2 to 8 days (Figure 2).

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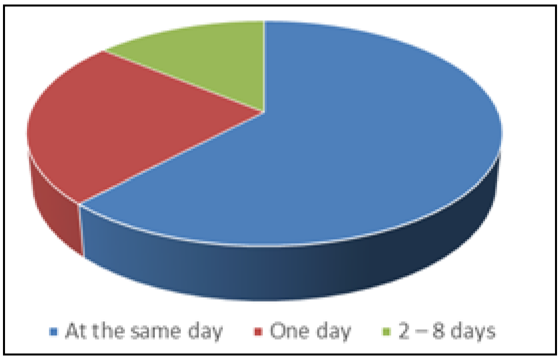


Figure 2: Pie chart showing distribution of patients according to time till surgery

According to fracture patterns of patients, forty percent had fracture type 3a and 24% had type 3b (figure 3).

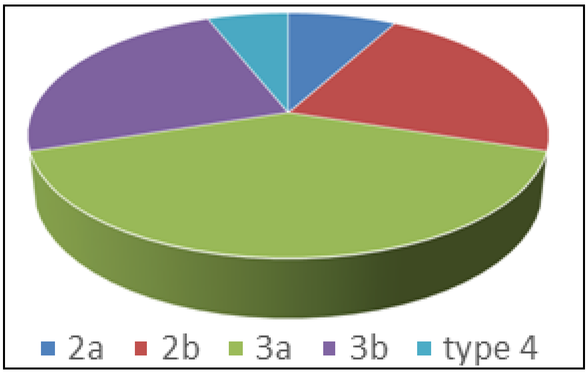


Figure 3: Pie chart showing distribution of patients according to type of fracture.

The intraoperative variables included time of surgery, medial condyle palpation, number of lateral pins, number of medial pins, predicted location of the ulnar nerve, actual location of the ulnar nerve. Intraoperative anteroposterior, Jones anteroposterior view, slight oblique view as well as lateral view used to evaluate accuracy of the reduction. All of the fractures were stabilized with 2 to 4 crossed K-wires. One lateral pin was used in 20 cases and 2 lateral pins were used in 30 cases; 1 medial pin was used in 48 cases and 2 medial pins were used in 2 cases. Seven Patients stayed in hospital for one to five days. forty-three patients stayed for one day (86%) (figure 4) Follow up was obtained every two weeks for the first 2 months. Time to full union in studied patients ranged from three to seven weeks. forty-four patients had complete union within 3 to 4 weeks (88%) (figure 5).

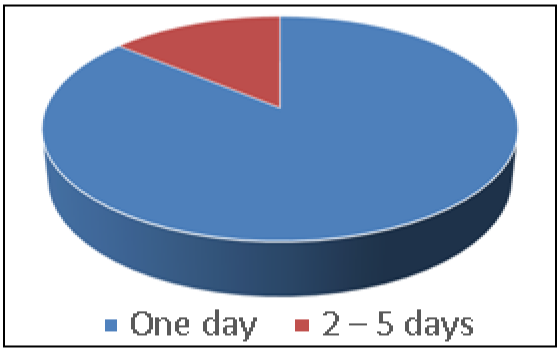


Figure 4: Pie chart showing distribution of patients according to length of hospital stay

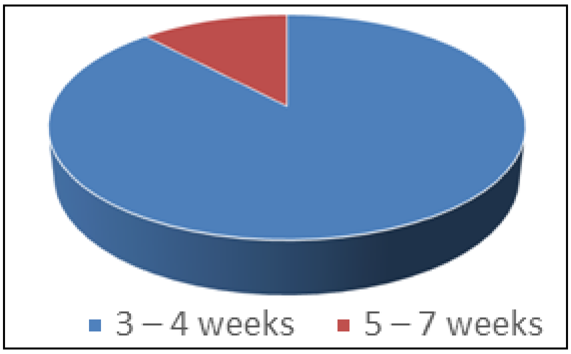


Figure 5: Pie chart showing distribution of patients according to time till complete union

Preoperative assessment:

Clinical assessment and radiographic evaluation: Each patient was properly examined preoperatively for the presence of neurovascular injury, sensory examination was done first to gain the confidence of the child since it will not cause pain. Pulp of the index finger was checked for median nerve sensation, followed by pulp of the little finger for ulnar nerve sensation and finally dorsum of the first web space for the radial nerve sensation. Motor function was assessed by "Paper, rock, scissors, OK" test for radial, median, ulnar, and anterior interosseus respectively. Some patients were delayed before surgery due to the presence of a medical problem or extensive edema that required control prior to surgery.

Surgical Procedure

All fifty patients received general anesthesia. Muscle relaxants causes muscle paralysis. In order to visualize nerve function through muscle contractions with the help of the peripheral nerve stimulator, muscle relaxants were not used. Closed reductions were not affected by the absence of muscle relaxants.

At the time of operation, following induction of general anesthesia, medial epicondyle was palpated first. Patients were placed in a supine position. C-arm image intensifier was introduced from the foot of the table lying parallel so the patient's arm can rest over it (Fig 6).

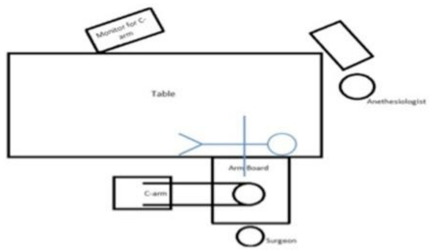


Figure 6: Suggested surgical room set-up

Longitudinal traction was applied first with the forearm supinated to dislodge the fracture and aintains length.

Following this, medial or lateral translation and angulation was corrected. A flexion reduction maneuver was then performed with pressure of the surgeon's thumb applied over the tip of the olecranon during elbow flexion. The elbow was then kept hyperflexed with forearm pronation to lock the reduction.

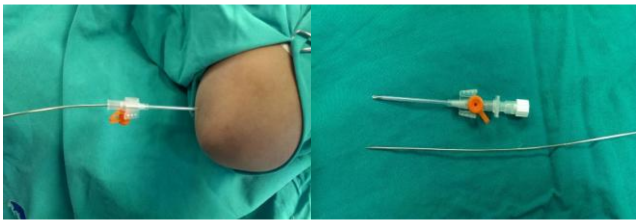
Medial displacement of the distal fragment often required pronation for stability, with the elbow flexed. While lateral displacement of the distal fragment frequently required supination for stability.

Jones anteroposterior view, slight oblique view as well as lateral view were obtained to confirm the reduction. Lateral view was obtained through external rotation of the arm unlike unstable fractures which needed the C-arm to be rotated rather than the arm.

A 1.6mm K-wire or larger smooth K-wire was prepared for pinning. Prior to placement of the medial pin, a mark was made on the skin with a pen at the predicted location of the ulnar nerve near the medial epicondyle with the elbow at 90°. A small-bore needle was inserted in a perpendicular manner to the skin on the predicted location of the ulnar nerve that has been visually assumed and marked.

The nerve stimulator cable was connected to the needle which acts as an electrode. The second electrode (standard skin-adhesive electrode) was applied transcutaneously by the anesthesiologist at a distal location. The nerve stimulator (Stimuplex HNS12) was set to the following parameters: Pulse frequency 2Hz, Pulse duration: 0.1ms, Current intensity: 0.5 gradually increasing to 2.0 mA. No twitch contractions of the little finges indicated that the predicted ulnar nerve position was inacurate.

The needle electrode was then reinserted closer to the medial epicondyle until a response in the form of little finger flexion was obtained. Actual position of the ulnar nerve was then marked. A wide bore orange cannula (14gauge) was then inserted to the bone of the medial epicondyle away from the actual location of the ulnar nerve. The needle of the cannula is then removed, and the cannula sheath was still placed in the same position to offer additional protection to the ulnar nerve.



Then a 1.6mm K-wire loaded on a power drill connected with the peripheral nerve stimulator cable was placed inside the cannula sheath and drilling was done under fluoroscopic control.

The distance in millimeters was then recorded from the medial pin to the predicted and actual location of the ulnar nerve, and the difference was calculated. Statistical analysis for the difference between these two measurements was done.

Statistical methods

Date was analyzed using IBM® SPSS® Statistics version 29 (IBM® Corp., Armonk, NY, USA) and MedCalc® version 20 (MedCalc® Software bvba, Ostend, Belgium)

Continuous numerical variables were described as mean and standard deviation, and median and discrete variables as median and interquartile range. Categorical variables were presented as number and percentage.

3. Results

Patients' characteristics variables included are age and genders were recorded. The mean age was 6.28 years.72% were males and 28% were females (Table 1).

Table 1: Distribution of studied patients according to demographic data

	N=50	**%**
Gender: Female Male	 14 36	 28% 72%
	Mean ± SD	**Range**
Age (year)	6.28 ± 2.36	2 – 11

Pre-operative findings showed five patients suffered from radial nerve deficit. Three recovered within 2 months and one after 3 months postoperatively. Intraoperatively medial epicondyle was palpated in all patients (Table 2).

Table 2: Median and range

	Median (IQR)	**Range**
Time to surgery (day)	0 (0 – 1)	0 – 8
	N=50	%
At the same day One day 2 – 8 days	31 12 7	62% 24% 14%
Medial epicondyle palpation	50	100%
Fracture pattern: 2a 2b 3a 3b 4	 4 11 20 12 3	 8% 22% 40% 24% 6%
Nerve deficits: None Radial nerve	 45 5	 90% 10%

Operative time among studied patients ranged from 30 to 90 minutes with mean 44.8 minutes. 60% of patients had two lateral pins while 40% had only one lateral pin (Table 3). Forty-eight patients had one medial pin (96%) and two patients (4%) had two medial and two lateral pins inserted.

Table 3: Distribution of studied patients according to operative data

	Mean ± SD	Range
Operative time (min)	44.8 ± 12.7	30 – 90
	N=50	%
Number of medial pins One Two	 48 2	 96% 4%
Number of lateral pins One Two	 20 30	 40% 60%

Regarding the predicted location and actual location of the ulnar nerve to medial epicondyle, results showed that mean predicted location of ulnar nerve was 9.24 mm (±3.76mm) while mean actual location was 7.02 mm (±3.13mm). Interclass correlation was 0.852 with 95% confidence interval -0.049 to 0.956 and Cronbach's alpha was 0.944 which reflects excellent agreement between both parameters.

Predicted Mean ± SD	Actual Mean ± SD	ICC	95% CI	Cronbach alpha	p
9.24 ± 3.76	7.02 ± 3.13	0.852	-0.049, 0.956	0.944	<0.001**

*p≤0.001 is statistically highly significant score of Cronbach alpha >0.7 is acceptable, >0.8 is good and >0.9 is excellent.

In all 50 cases no cases of iatrogenic ulnar nerve injury were observed using this surgical technique. Concerning complications, forty-four patients (82%) passed non-complicated, six patients (12%) had pin tract infection and three (6%) had pre-operative radial nerve injury. (Table 4)

Table 4: Complication rate

	N=50	%
Complications: None Pin tract infection	 44 6	 88% 12%

Regarding the relation between postoperative complications and demographic data, a chi square test was used showing there is statistically non-significant relation between incidence of postoperative complications and either gender or age (Table 5).

Table 5: Relation between postoperative complications and demographic data

Parameter	Complications		χ^2/t	p
	Complicated	Non-complicated		
	N=9(%)	N=41(%)		
Gender: Female Male	 3 (33.3%) 6 (66.7%)	 11 (26.8%) 30 (72.2%)	Fisher	0.697
	Mean ± SD	Mean ± SD	t	p
Age (year)	8.56 ± 3.88	9.39 ± 3.76	-1.019	0.313

χ^2chi square test t independent sample t test

Concerning the relation between postoperative complications and preoperative data chi square test and Mann Whitney test were used (Table 6). There is statistically significant relation between incidence of postoperative complications and preoperative nerve deficit (33.3% with complicated versus 4.9% of non-complicated had radial nerve injury). There is statistically non-significant relation between incidence of postoperative complications and either type of fracture or time till surgery.

Table 6: Relation between postoperative complications and preoperative data

Parameter	Complications		χ^2	p
	Complicated	Non-complicated		
	N=9(%)	N=41(%)		
Fracture pattern:				
2a	0 (0%)	4 (9.8%)	0.088	0.767
2b	3 (33.3%)	8 (19.5%)		
3a	4 (44.4%)	16 (39%)		
3b	2 (22.2%)	10 (24.4%)		
4	0 (0%)	3 (7.3%)		
Nerve deficits:				
None	6 (66.7%)	39 (95.1%)	Fisher	0.035*
Radial nerve	3 (33.3%)	2 (4.9%)		
	Median(IQR)	Median(IQR)	Z	p
Time till surgery	0 (0 – 1)	0 (0 – 1)	-0.38	0.704

Relation between postoperative complications and operative data showed there is statistically non-significant relation between incidence of postoperative complications and either operative time, number of medial or lateral pins (Table 7).

Table 7: Relation between postoperative complications and operative data

Parameter	Complications		χ^2	p
	Complicated	Non-complicated		
	N=9(%)	N=41(%)		
Medial pins				
One	9 (100%)	39 (95.1%)	Fisher	>0.999
Two	0 (0%)	2 (4.9%)		
Lateral pins				
One	5 (55.6%)	15 (36.6%)	Fisher	0.454
Two	4 (44.4%)	26 (63.4%)		
	Mean ± SD	Mean ± SD	t	p
Operative time	45.0 ± 10.61	44.76 ± 13.23	0.052	0.959

χ2chi square test t independent sample t test

There is statistically significant relation between incidence of postoperative complications and time till union (significantly higher in complicated patients).

There is statistically non-significant relation between incidence of postoperative complications and hospital stay (Table 8).

Table 8: Relation between postoperative complications and postoperative events data

Parameter	Complications		t	p
	Complicated	Non-complicated		
	Mean ± SD	Mean ± SD		
Time to union	5.11 ± 1.05	3.83 ± 0.38	3.597	0.006*
	Median(IQR)	Median(IQR)	Z	p
Hospital stay	1 (1 – 1)	1 (1 – 1)	-0.356	0.722

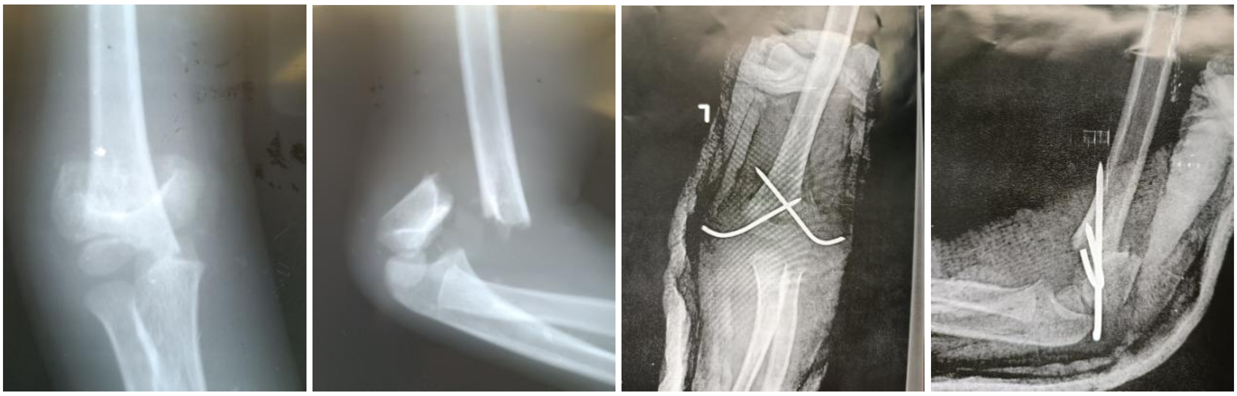
Case no 31:

Patient profile: Female patient, 9 years old, student, fell on outstretched hand. She developed right side supracondyar fracture of the humerus. She has irrelevant medical history. She was addmited to another hospital where closed reduction and percutanous pinning was done on the same day. Patient came to us the next day in the outpatient clinic as she was worried about the post-operative x-ray. Patient was admitted and operative revision of the fracture was performed on the same day.

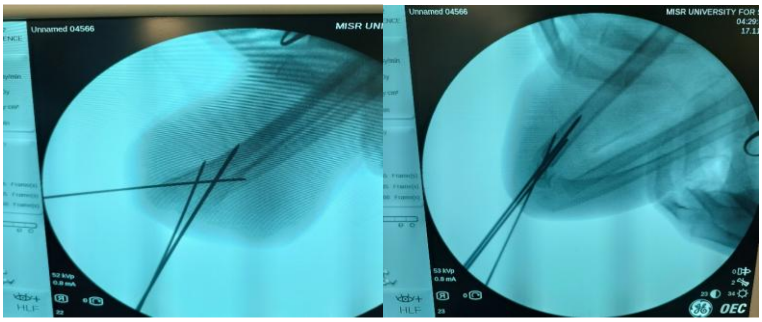
- **Fracture classification:** Gartland 3
- **Intraoperative difficulties:** none
- **Opeative time:** 45 minutes

Intraoperative measurments:

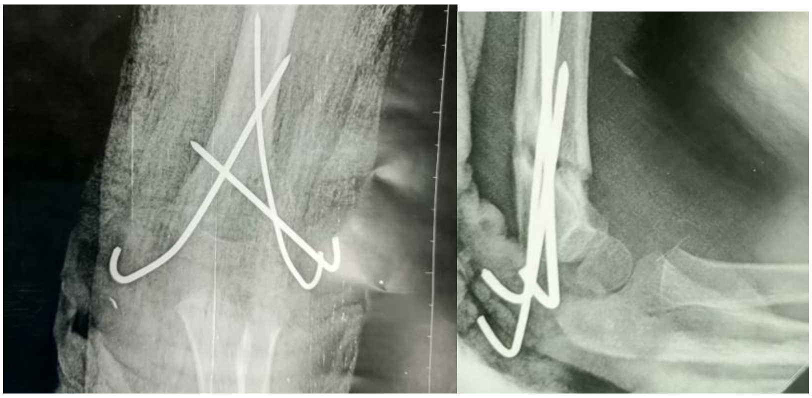
- **Predicted ulnar nerve location:** 14mm
- **Actual ulnar nerve location:** 11mm
- **Difference in millimeters:** 3mm
- **Number of lateral pins:** two
- **Number of medial pins:** One
- **Complications:** None
- **Postoperative hospital stay:** 1 day
- **Time to full union in weeks:** 4 weeks



Preoperative X-rays Lateral and AP views



Intraoperative Imaging



Follow up radiographs

4. Discussion

Fractures around the elbow joint represent ∼10% of all paediatric orthopaedic injuries, and supracondylar humeral fractures account for 50–70% of all elbow fractures. The treatment depends on the degree of the fragment displacement and the presence of a neurovascular injury**.**[17]An accepted classification of these fractures is the AO/Gartland system, as modified by **Wilkin.**[18] In accordance with this classification, some type II fractures and all type III and IV fractures require surgical intervention.

There are various treatment modalities for the supracondylar fractures of the humerus in children including closed reduction and casting, open reduction and internal fixation and percutaneous pinning. Closed reduction with percutaneous pin fixation is widely accepted, has become the treatment of choice for displaced supracondylar paediatric humeral fractures and and gives the lowest rate of residual deformity and lowest rate of compartment syndromes of forearm.[19]

Controversy exists about the optimal K-wire configuration in the fixation of Gartland's type II and III fractures. Two principal configurations have appeared in the literature: crossed pins (medial and lateral) and two lateral pins.[20]

The classic medial–lateral cross-wire technique involves the placement of two ascending K-wires, one inserted through the lateral condyle and another through the medial condyle. With this technique, the ulnar nerve may be injured by the medial wire as it is passed through the medial condyle. Ulnar nerve injury rates of up to 6–8% have been reported.[21]

A reason for the increased incidence of ulnar nerve injury includes the proximity of the medial pin to the nerve, resulting in direct penetration, contusion, or kinking. This has led to advocate closed reduction with only lateral pin fixation or medial pin fixation following visualization of the ulnar nerve via a small incision.[22]

There is a lack of consensus regarding the optimal number and position of pins necessary to satisfy these 2 requirements. Injury to the ulnar nerve while inserting the medial pin is a major concern during the percutaneous cross-pinning of supracondylar fractures and its incidence is reported to range from 1.4% to 20%. This type of injury is most likely caused by difficulty in identifying the location of the ulnar nerve through palpation before surgery, because of the significant posttrauma swelling.[23]

Several strategies have been suggested to avoid such ulnar nerve injuries. These include placing only lateral pins, even though this may compromise the mechanical stability of the fracture. Appropriate control of elbow flexion/extension during pin insertion may prevent the ulnar nerve injury. Limited exploration of the ulnar nerve during the insertion process has also been shown to reduce the incidence of the nerve injury.[24]

To achieve stability and avoid ulnar nerve injury, a modified version of the cross-wire technique, lateral crossed pin fixation with ascending and descending K-wires (Dorgan's lateral cross-wiring), has been proposed, where cross-wire fixation is achieved solely from the lateral side.[25]

The use of electrical stimulation to test the ulnar nerve continuity before and/or during pin insertion has been described in 2 earlier studies.[26,17] **Wind et al.**[26] reported a series of 34 patients who underwent closed or open reduction with no ulnar nerve injury when localizing the nerve before the insertion of the medial pin.

Our study is done in light of the high incidence of iatrogenic ulnar nerve injury reported because of insertion of the medial pin at the cross pin fixation.[27]There have been only a few reported cases of iatrogenic ulnar nerve injury following medial pin fixation. Therefore, the aim of this work is to assess the accuracy, feasibility, and reliability of the peripheral nerve stimulator during and after medial pin placement in surgical management of supracondylar fractures in children.

This prospective interventional clinical trial was conducted on 50 children with supracondylar fracture of humerus; in the Orthopedics Department of Suad Kafafi Teaching Hospital, Misr University for Science and Technology, School of Medicine, Cairo, Egypt. All patients were subjected to complete clinical picture and careful clinical examination**.** All patients needed X-ray films; AP/lateral view.

In our study, age was distributed as 6.28 ± 2.36 years with minimum of 2 years and maximum of 11 years. Regarding sex distribution, male represents majority with 72% and female with 28%. Also, **Shtarker et al.**[28]described the use of electrical stimulation concurrent with medial pin insertion as a monitoring technique for avoiding iatrogenic ulnar nerve injury in 138 children; 88 boys and 50 girls, with an average age of 5.6 years (SD ± 2.5, range 1 to 13).

Median time before surgery was zero with minimum of zero and maximum of 8 days. **Shtarker et al.**[28]kept all patients with the fractured elbow elevated for an average of 4 days from arrival at the hospital (SD±2.13) to allow the swelling to subside.

Intraoperatively, medial epicondyle was palpated in all patients, this was in agreement with **Wind et al.**[26] who assessed the ability to clinically predict the location of the ulnar nerve prior to percutaneous medial pin fixation and therefore to prevent nerve injury; however, the ulnar nerve was not definitively palpable in 7 of 22 cases, and thus the predicted value was made on a presumed location.

In our study, 4 were classified as type 2a pattern and 11 as type 2b pattern; 20 were classified as type 3a pattern and 12 as type 3b pattern; and 3 were classified as type 4 pattern. **Shtarker et al.**[28] found that 38 were classified as type II fractures and 100 as type III fractures; and 126 were extension type and 12 flexion type.

Pre-operative findings showed five patients suffering from radial nerve deficit. Three patients were recovered within 2 months and one patient was recovered after 3 months postoperatively. **Wind et al.**[26] found three patients with motor and sensory loss of the radial nerve, and one patient with a thready radial pulse.

Operative time among studied patients ranged from 30 to 90 minutes with mean 44.8 minutes. 60% of patients had two lateral pins while 40% had only one lateral pin. Forty-eight patients had one medial pin (96%) and two patients (4%) had two medial and two lateral pins inserted. Also, **Shtarker et al.**[28] stabilized all of the fractures with 2 to 4 crossed K-wires. One lateral pin was used in 84 cases and 2 lateral pins were used in 54 cases; one medial pin was used in 122 cases and 2 medial pins were used in 16 cases.

Skaggs et al.[20] studied 124 consecutively managed children. Fifty-five children had a type III fracture: nineteen (35%) of those fractures were stabilized with two lateral pins and thirty-six (65%) with three lateral pins and there were no iatrogenic ulnar nerve injuries, and no reduction was lost. They concluded that the use of lateral entry pins alone was effective for even the most unstable supracondylar humeral fractures.

Regarding the predicted location and actual location of the ulnar nerve to medial epicondyle, mean predicted location of ulnar nerve was 9.24 mm (±3.76mm) while mean actual location was 7.02 mm (±3.13mm). Interclass correlation was 0.852 with 95% confidence interval -0.049 to 0.956 and Cronbach's alpha was 0.944 which reflects excellent agreement between both parameters.

Wind et al.[26] found that the average predicted distance from the ulnar nerve to the medial pin was 9.3 ± 3.4 mm (mean ± SD; range 1–15), whereas the actual distance from the ulnar nerve to the pin measured 7.6 ± 3.7 mm (range 0–15), for a difference of 1.7 mm (range 0–4 mm). In one instance, stimulation of the medial pin resulted in an ulnar nerve response. The pin was repositioned and subsequent stimulation resulted in no response.

In all 50 cases, no cases of iatrogenic ulnar nerve injury were observed using this surgical technique. Concerning complications, forty-four patients (82%) passed non-complicated, six patients (12%) had pin tract infection and three (6%) had preoperative radial nerve injury. In agreement with our study, **Michael and Stanislas**[29] were the first to describe the continuous ulnar nerve stimulation throughout the surgical procedure and they reported no iatrogenic ulnar nerve injury in 10 children. They found that this technique is suitable for routine use in children undergoing percutaneous K-wire stabilization of the supracondylar fractures of the humerus. Altematively, it could be used selectively when severe swelling obscures the bony landmarks of the elbow and/or the surgeon is inexperienced.

Also, **Shtarker et al.**[28] observed no cases of iatrogenic ulnar nerve injury, secondary fracture displacement, compartment syndrome, pin migration, or pin tract infection. The only postoperative complication detected involved 2 cases of anterior interosseus nerve neuropraxia, which resolved spontaneously after 4 to 6 months.

But, **Royce et al.**[30] reviewed 143 supracondylar humerus fractures and disclosed three iatrogenic ulnar nerve injuries, all of which resolved. They recommended making a small incision over the medial epicondyle prior to placing the medial pin. They also stated that iatrogenic ulnar nerve injury from the medial K-wire is more common than indicated in the literature.

Brown and Zinar[31]reported four ulnar nerve injuries in their series of 162 supracondylar humerus fractures treated with internal fixation. All four cases of iatrogenic ulnar nerve palsy were re-explored and the nerve was consistently injured by the medial pin. All injuries resolved spontaneously by 6 months, with an average of 2.3 months.

Lyons et al.[32] had 19 postoperative ulnar nerve palsies from pin fixation of 375 supracondylar humerus fractures. Follow-up of 17 of these patients revealed complete return of function with only 4 of the 17 pins removed. They concluded that ulnar nerve injuries occurring after percutaneous pin fixation of supracondylar humerus fractures usually resolve spontaneously. However, **Rasool**[33] reported six cases of ulnar nerve injury resulting from crossed K-wire fixation, with no recovery in one patient at 14 months of follow-up.

Concerning the relation between postoperative complications and preoperative data, there is statistically significant relation between incidence of postoperative complications and preoperative nerve deficit (33.3% with complicated versus 4.9% of non-complicated had radial nerve injury). There is statistically significant relation between incidence of postoperative complications and time till union (significantly higher in complicated patients).

Wind et al.[26] stated that three patients with documented radial nerve deficits preoperatively showed continued motor and sensory radial nerve changes but recovered within 2 months postoperatively. Other two patients, one with a decreased radial pulse and the other with ulnar sensory symptoms, were free of neurovascular complications postoperatively. **Shtarker et al.**[28] achieved primary fracture healing in all 138 cases without nonunions or delayed unions.

Lee et al.[34] indicated the superiority of cross-pin fixation for the purposes of mechanical stability in the supracondylar fractures in children. A loss in mechanical stability can result in postsurgical complications, particularly nonunion and deformity, which may have a high impact on the quality of life and the performance of physical activities of daily living, especially in growing children. However, the main disadvantage of cross-pin fixation is the potential risk for iatrogenic ulnar nerve injury during the insertion of the medial pin.

Owing to this possible complication, there is growing interest in substituting medial pinning with lateral pinning, which is claimed to be sufficient for ensuring mechanical stability of the fracture. Nevertheless, even strong advocates of lateral pinning agree that cross-pin fixation is indispensable in some cases such as those involving complete displacement or medial-rotatory instability.[35]

The current results suggest that monitoring the ulnar nerve during cross-pin insertion can solve this dilemma by providing stability, while at the same time avoiding the risk for iatrogenic ulnar nerve injury.

Extreme flexion is essential for achieving temporary stable fixation during pin insertion, particularly in unstable fractures where instability is present in more than 1 plane. However, it has been suggested that extreme elbow flexion during fixation should be avoided to decrease the negative effect of this position on the mobility and morphologic characteristics of the ulnar nerve.[25]

Therefore, it has been suggested that the lateral pins should be inserted first in full elbow flexion. This would achieve temporary stability at which time the medial pin can be inserted in full elbow extension. Nevertheless, in an unstable fracture, inserting the medial pin first provides the important advantage of enabling rigid alignment and proper fixation.[36]**Queally et al.**[37] attributed iatrogenic ulnar nerve injury to hypermobility of the nerve or constriction of the cubital tunnel.

Another advantage to using the ulnar nerve stimulation is its contribution to the diagnosis of nerve injury before surgery. There is general agreement that it may be difficult to determine nerve status prereduction in many cases, particularly in severe fractures, because of the child's distress, pain, and lack of cooperation. Therefore, the absence of the ulnar nerve response to stimulation before pin insertion can be used to determine the need for ulnar nerve exploration.[38]

We agreed with the observations of **Wind et al.**[26] that injury to the ulnar nerve during blind pinning of supracondylar humerus fractures is common. The technique of ulnar nerve localization with stimulation of a small needle prior to pin placement, or stimulating the medial pin after placement to confirm it has not contacted the nerve, may result in a decreased risk of nerve injury.

Ulrich et al.[39] suggested that anterior interosseus nerve injury after supracondylar fracture is more common than previously recognized. **Shtarker et al.**[28] concluded that ulnar nerve stimulation before and during the percutaneous pinning of supracondylar fractures in children is a simple, economical, and easy-to-implement technique that can prevent iatrogenic ulnar nerve injury.

5. Conclusion

The percutaneous pinning technique of paediatric supracondylar humeral fractures is similar to the conventional cross-wire technique in terms of the fracture stability, but superior in terms of ulnar nerve safety. Also, it is similar to other lateral entry techniques in avoiding ulnar nerve injury, but it is superior in achieving fracture stability. It could be considered as a viable option for treating displaced supracondylar fractures in children. Fixation of the pediatric supracondylar humeral fractures by using lateral entry pinning or medial-lateral entry pinning is without difference in prevention of complications and gets the best outcome of the patient. Finally, we can say that peripheral nerve stimulator prevents iatrogenic ulnar nerve injury around the elbow in the surgical treatment of supracondylar fractures in children during medial pin placement.

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