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Supracondylar Osteotomy for the Treatment of Post-Traumatic Cubitus Varus in Children: Long-Term Results and Comparison of Two Different Fixation Methods

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Abstract

Cubitus varus is the most common complication of supracondylar fractures in children. The purpose of this study was to analyze the long-term results of valgus osteotomy for the treatment of this condition and to compare two different fixation methods of the osteotomy site. A retrospective, IRB approved review was conducted on 48 children who underwent supracondylar osteotomy for posttraumatic cubitus varus. Two groups with different internal fixation methods were compared: Group A: isolated K-wire construct, and Group B: augmented construct using k-wires with either a Blount staple or an 8-plate. Clinical and radiological parameters were measured and compared between both groups and complications were included. Statistical analysis was done using Chi-square test, ANCOVA test, Mann-Whitney U test and Friedman test. Age at surgery was 4±1.8 years, with a mean follow up of 10±4.5 years.

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Patients showed a significant post-operative increase in active flexion compared to preoperative values (140° vs 122°, $p < 0.0001$). Clinical carrying angle was 5° of valgus postoperatively vs 18° of varus preoperatively ($p < 0.0001$). Radiological carrying angle was 7° of valgus postoperatively vs 18° of varus preoperatively ($p < 0.0001$). A mean clinical and radiological carrying angle correction of 22° and 25°, respectively, was achieved. No statistically significant differences were found between the K-wire and augmented construct groups concerning flexion, extension, carrying angle, gain of flexion, gain of extension, and gain of carrying angle, and total incidence of complications; hypertrophic scar events were however more present in group A. Both groups yielded comparable excellent, good and poor results, yet patient satisfaction was better in Group B. Implementing an augmented construct in older patients was thought to counteract the varus moment and provide a more stable osteotomy. However, correction was comparable between both groups. Furthermore, no benefit was found in reducing complication rates, increasing range of motion and overall clinical results. We find it therefore difficult to recommend a rigid construct systematically in all patients. Supracondylar lateral closing wedge osteotomy yielded overall excellent/good long-term outcomes. Major complications were rare. No benefit concerning range of motion and carrying angles was procured in augmenting a K-wire construct with an 8-plate or Blount staple. However, K-wire + 8-plate/staple constructs displayed less hypertrophic scar events and more overall satisfaction. Complication rates and clinical results were comparable no matter the montage employed.

Keywords: Blount staple; carrying angle; cubitus varus; elbow supracondylar valgus osteotomy; K-wire; 8 plate.

1. Introduction

Cubitus varus is the most common complication in children sustaining a supracondylar humeral fracture. It is a triplanar deformity consisting of varus angulation in the coronal plane, internal rotation in the axial plane and extension in the sagittal plane [1].

This deformity rarely limits function but produces an unsightly appearance that does not improve with bone remodeling [2]. This acts as a prominent psychological stressor for the child and his parents, and as a result is the primum movens for consultation.

Various osteotomy techniques have been developed to address cubitus varus, including the lateral closing wedge-osteotomy (LCWO) most commonly used because of its simplicity, step-cut osteotomy, dome osteotomy, multiplanar osteotomy and many more [3,4]. No single technique is statistically safer or more effective than any other and no gold standard currently exists [4]. However, long-term results of the LCWO, have been described in multiple studies with overall very good functional outcomes [4,5,6]. This further stresses that a simple technique such as LCWO yields a stable osteotomy site with overall good outcomes without having to rely on multiplanar osteotomies which are complicated to execute [4]. Therefore, LCWO was opted as the standard procedure in our study.

With the wide diversity of osteotomy techniques comes an equally wide variety of constructs including Kirschner wires, Kirschner wires with figure-8 wire loop, staples, screws, screws with figure-of-8 wire loop, plates, even external fixation [7]. Multiple constructs can also be combined to stabilize the osteotomy site.

Few studies compare the various methods of fixation of the osteotomy [2]. We therefore aimed to compare isolated k-wires with augmented constructs consisting of plate and screws or Blount staple combined with K-wires in supracondylar valgisation osteotomy. We analyzed post-operative range of motion values, complication rates and overall functional outcomes between both groups. Another goal was to compare the long-term post-operative maximal flexion, extension, clinical and radiological carrying angles vis-à-vis preoperative and contralateral side measurements.

2. Materials and methods

2.1. Study description

This is an IRB approved, cross-sectional descriptive study undergone on patients who had previously presented to a single institution between 1999 and 2019 for cubitus varus who were operated of supracondylar valgus osteotomy.

Subjects had previously signed an informed consent form allowing the use of their medical information for research purposes.

2.2. Patient selection

Inclusion criteria were the following: Cubitus varus following a supracondylar elbow fracture that was treated conservatively or surgically and age < 16 years at time of supracondylar valgus osteotomy. The exclusion criterion was history of supracondylar osteotomy. All included patients were contacted and asked to present for follow-up.

2.3. Surgical technique

All subjects were operated of a lateral closing wedge osteotomy (LCWO) for correction of the cubitus varus following a triceps-sparing approach.

A posterolateral approach was performed, with dissection of the intermuscular plane formed by the triceps and brachioradialis. Incision and reflection of the lateral periosteum, exposing the distal humerus and varus malunion site (Figure 1).

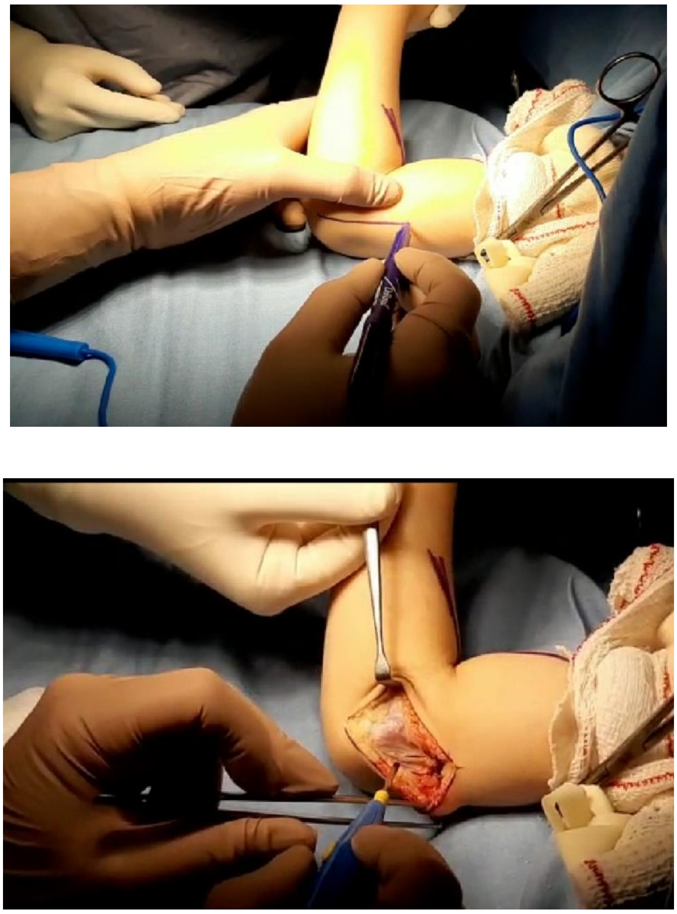

Figure 1: The triceps-sparing approach for lateral closing wedge supracondylar osteotomy

First, distal osteotomy is performed perpendicular to the articular surface at the upper margin of the olecranon fossa. A more proximal oblique osteotomy is made to create the desired angle of lateral wedge which is then removed. Closure of the osteotomy site is done with the elbow extended. Ulnar translation of the distal fragment was done until the lateral cortices were perfectly overlapping. Fixation is done using parallel lateral k-wires which did not protrude through the skin. In case of an augmented construct, 8-plate + 2 bicortical 3.5 mm screws and 2 parallel k-wires distal to the plate from lateral to medial are applied. Fluoroscopic control is done at the end of procedure. (Figure 2-3).

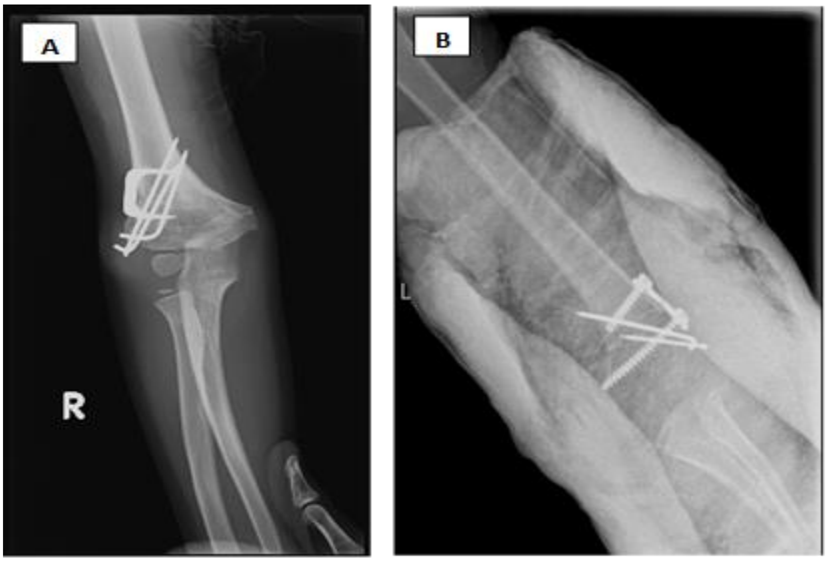

Figure 2A: Anteroposterior radiograph of an elbow supracondylar osteotomy taken prior to hardware removal, fixed with an augmented construct using K-wires and a lateral Blount staple

Figure 2B: Anteroposterior radiograph of an elbow supracondylar osteotomy taken at 6 weeks post-op. A lateral 8-plate and K-wires were employed

Figure 2C: Anteroposterior and lateral view radiograph of an elbow supracondylar osteotomy taken at 6 weeks post-op. K-wires were employed

Figure 3: Fluoroscopic control of a supracondylar osteotomy. Notice the complete osteotomy reaching the ulnar cortex and the medial translation of the distal fragment until lateral cortices are aligned. This technique prevented lateral condyle prominence

2.4. Post-operative protocol

After surgery, a long-arm cast was applied with the elbow at 90° of flexion and the forearm in neutral rotation for a period of 6 weeks. Radiological follow-up was performed at the 6-week mark. The cast was removed at 6 weeks and active and passive range of motion were initiated. The hardware was removed systematically after 6 months.

2.5. Data collection

Various clinical and demographic data were collected from patients at presentation and final follow-up, these are summarized in Table 1.

Table 1: Study sample characteristics

Variables	n/mean/%/Post-Op Values
Total number of patients included	48
Male	31 (64.6%)
Female	17 (35.4%)
Mean age of fracture (years)	4.1
Mean age of SCO (years)	4
Mean follow-up (years)	9.6
3K-wires construct (%)	19 (39.6%)
K-wires + 8-plate/stapler (%)	29 (60.4%)
Osteotomy Technique, LCWO (%)	48 (100%)
Radial Neuropathy (%)	2 (4.1%)
Median Neuropathy (%)	0
Ulnar Neuropathy (%)	1 (2%)
Residual Varus (%)	5 (10.4%)
Osteomyelitis (%)	0
Iatrogenic Epiphysiodeses (%)	0
Hardware Failure/Nonunion (%)	0
Vascular Injury (%)	0
Hypertrophic Scar (%)	23 (47.9%)
Edema (%)	28 (58.3%)
Surgical Site Infection (%)	9 (18.7%)
Lateral Condyle Prominence (%)	6 (12.5%)
Carrying Angle < 5° of Valgus (%)	18 (37.5%)
Total Complications	92
Major Complications (%)	8 (16.6%)
Nerve Injuries (%)	3 (6.2%)
Nerve Injuries Unresolved (%)	0

Mean Post-Op Flexion	139.8°
Mean Post-Op Extension	-5.5°
Mean Post-Op Clinical Carrying angle	5°
Mean Post-Op Radiological Carrying Angle	7.1°
Mean Gain of Flexion	16°
Mean Gain of Extension	-9°
Mean Gain of Clinical Carrying Angle	22°
Mean Gain of Radiological Carrying Angle	24.9°
Excellent Clinical Results (n/%)	34/70.8%
Good Clinical Results (n/%)	13/27%
Poor Clinical Results (n/%)	1/2.1%
Overall Patient Satisfaction (n/%)	43/89.6%
Overall Patient Dissatisfaction (n/%)	5/10.4%

At final follow-up, a physical exam of both elbows was performed and the following findings were recorded: Surgical wound scar inspection; clinical carrying angle (in °); maximal active elbow range of motion including flexion and extension (in °).

Forearm axis is defined by the line passing through the mid distance between the medial and lateral epicondyle of humerus proximally, and the mid-distance between the ulnar and radial styloid. The clinical carrying angle is the angle created by these two axis, measured by the goniometer in a supine position. The same principles are applied for flexion and extension, measured in standing position. All subjects then underwent anteroposterior and lateral radiographs of the elbow and the radiological carrying angle or the Humerus-Elbow-Wrist angle (HEW angle) is measured on the true anteroposterior radiograph. This angle was adapted for its reliability and validity [14] and superiority over the humero-ulnar and Baumann angles [9]. It is defined as the angle between the longitudinal axis of the humeral shaft and a line passing through the midpoints of 2 transverse lines across the forearm. A HEW angle of < 5° indicates cubitus varus. All clinical and radiographic measurements were undertaken by a single final year orthopedic resident.

Post-operative complications encountered during follow-up were subdivided into major and minor complications. Clinical results were classified as Excellent, Good or Poor [1]. Instead of strictly employing Laupattarakasem's [15], Oppenheim [9], Bellemore [6] and many more reported criterias to assess the final results, we opted for a more wholesome outcome summary based on reported variables and including Barrett's questionnaire [6] (Table. 2). Two or more criterias are enough to classify patients accordingly (Table. 3).

Table 2: This questionnaire assesses patient's satisfaction with the cosmetic outcomes of supracondylar osteotomy. Satisfaction is noted when the patient is pleased or slightly bothered with the overall appearance of the operated elbow. Dissatisfaction is noted when the patient is completely bothered by the appearance

Barrett's Questionnaire	Yes	No
Does your child's arm look crooked?		
Do you or your child notice a bump?		
Does the bump bother you or your child?		
Do you or your child notice the operation scar?		
Does the scar bother you or your child?		
Are you or your child pleased with the result?		
Would you repeat the operation if given the same circumstance?		

Table 3: Overall clinical results post-supracondylar osteotomy. Two or more criterias are enough to classify patients accordingly

Excellent Result	Good Result	Poor Result
No Relapse		
Correction of the Varus Deformity to Within 5° of the Contralateral Elbow	Correction of the Varus Deformity to Within 10° of the Contralateral Elbow	Perceivable Cubitus Varus
No Major Complications	No Major Complications	Major Complication Requiring Surgery
Patient Satisfaction	Patient Satisfaction	Patient Dissatisfaction
		Perceivable Limitation of ROM

Post-operative clinical and radiological data were compared to preoperative values and contralateral side values.

Complications, range of motion, carrying angles, clinical results and overall patient satisfaction were compared and analyzed between group A and B.

2.6. Statistical analysis

In order to assess differences in demographics between the treatment groups, a Mann-Whitney U test was computed for age, and a Chi-square test for sex.

In order to assess the differences between pre-operative, post-operative and contralateral results in both treatment groups, a Friedman test with multiple pairwise comparisons using a Nemenyi procedure was undertaken. In order to assess the differences in complication rates between the two groups, a Chi-square test is applied. In order to assess differences between the two treatment groups, results were compared using an ANCOVA test with Tukey pairwise comparisons was run while controlling for confounding factors. *p-value* of less than 0.05 is significant.

3. Results

A total of 48 subjects met the inclusion criteria and were included in the study.

3.1. Overall Long-Term Clinical Outcomes (Table 4-5)

Concerning major complications, all nerve palsies fully recovered with no sequelae.

Osteomyelitis, iatrogenic epiphysiodesis, hardware failure, nonunion and vascular lesions were absent in all subjects.

Patients mainly exhibited minor complications: 23 (47.9%) complained of a hypertrophic scar, 28 (58.3%) noted edema in their lateral and anterior elbow region creating a pseudoprominence of the lateral condyle, which 6 (12.5%) patients truly had by calculating the Lateral Prominence Index (values not shown). 9 (18.7%) patients suffered from superficial surgical scar infection which were all treated successfully with wound care and oral/topical antibiotics.

Concerning active elbow flexion, the mean preoperative measure is 122°. This angle increases to a mean value of 139.8° in the post-operative setting which is less than the mean angular value of the contralateral side by 9° (148.8°). This increase is statistically significant ($p < 0.0001$, $p = 0.005$ respectively). Mean gain of postoperative flexion is 16°, yet 7 (14.6%) patients have experienced a mean loss of 6° of active flexion.

No statistically significant difference is seen in the extension angle between the preoperative and post-operative setting ($p = 0.533$), and the postoperative and contralateral setting ($p = 0.083$). A mean loss of 9° of postoperative extension is observed which translates to diminished recurvatum.

Mean clinical carrying angle is significantly improved from 18.4° of varus to 5° of valgus (post-operative value) ($p < 0.0001$) versus 10° of valgus (contralateral value) ($p < 0.0001$).

Same goes for the radiological carrying angle with a statistically significant improvement from a mean of 17.9° of varus to 7.1° of post-operative valgus ($p < 0.0001$).

Gain of both clinical and radiological carrying angle was clearly observed, with a main gain of 22° and 24.9° respectively. The contralateral radiological carrying angle was discarded in this study to prevent further patient radiation exposure.

34 (70.8%) patients had excellent clinical outcomes, 13 (27%) patients had good outcomes, and only one patient (2.1%) had a poor result with residual post-operative varus perceived and aesthetically bothersome.

43 patients (89.6%) displayed overall satisfaction, and only 5 (10.4%) patients were not satisfied with the surgical outcome.

Table 4: Major and minor complications

Major Complications	**Minor Complications**
Neuropathy (Median, Ulnar, Radial)	Hypertrophic Scar
Residual Varus	Edema
Osteomyelitis	Surgical Site Infection
Iatrogenic Epiphysiodeses	Lateral Condyle Prominence
Hardware Failure/Nonunion	Carrying Angle < 5° Valgus
Vascular Lesion	

Table 5: Mean post-operative flexion, extension, radiological and clinical carrying angles were compared to the pre-operative and contralateral side values. An increase of maximal flexion and carrying angles is noted compared to preoperative values, yet contralateral measurements remain superior. A significant result is outlined in Bold

Variables	**Post-op Values**	**Pre-op Values**	**Contralateral Side Values**	***p-value*** **; preoperative comparison, contralateral side comparison**
Mean Post-Op Flexion	139.8°	122.3°	148.8°	***p < 0.0001, p = 0.005***
Mean Post-Op Extension	-5.5°	-4.1°	-6.8°	*p = 0.533, p = 0.083*
Mean Post-Op Clinical Carrying Angle	5°	18.4°Varus	10°	***p < 0.0001, p < 0.0001***
Mean Post-Op Radiological Carrying Angle	7.1°	17.9° Varus	_	***p < 0.0001***

3.2. Long-Term Clinical Outcomes of Two Different Fixation Methods (Table 6)

19 patients were randomly assigned to Kirschner wires fixation (Group A, Figure 4) and 29 to Kirschner wires and 8 plate/staple (Group B, Figure 5).

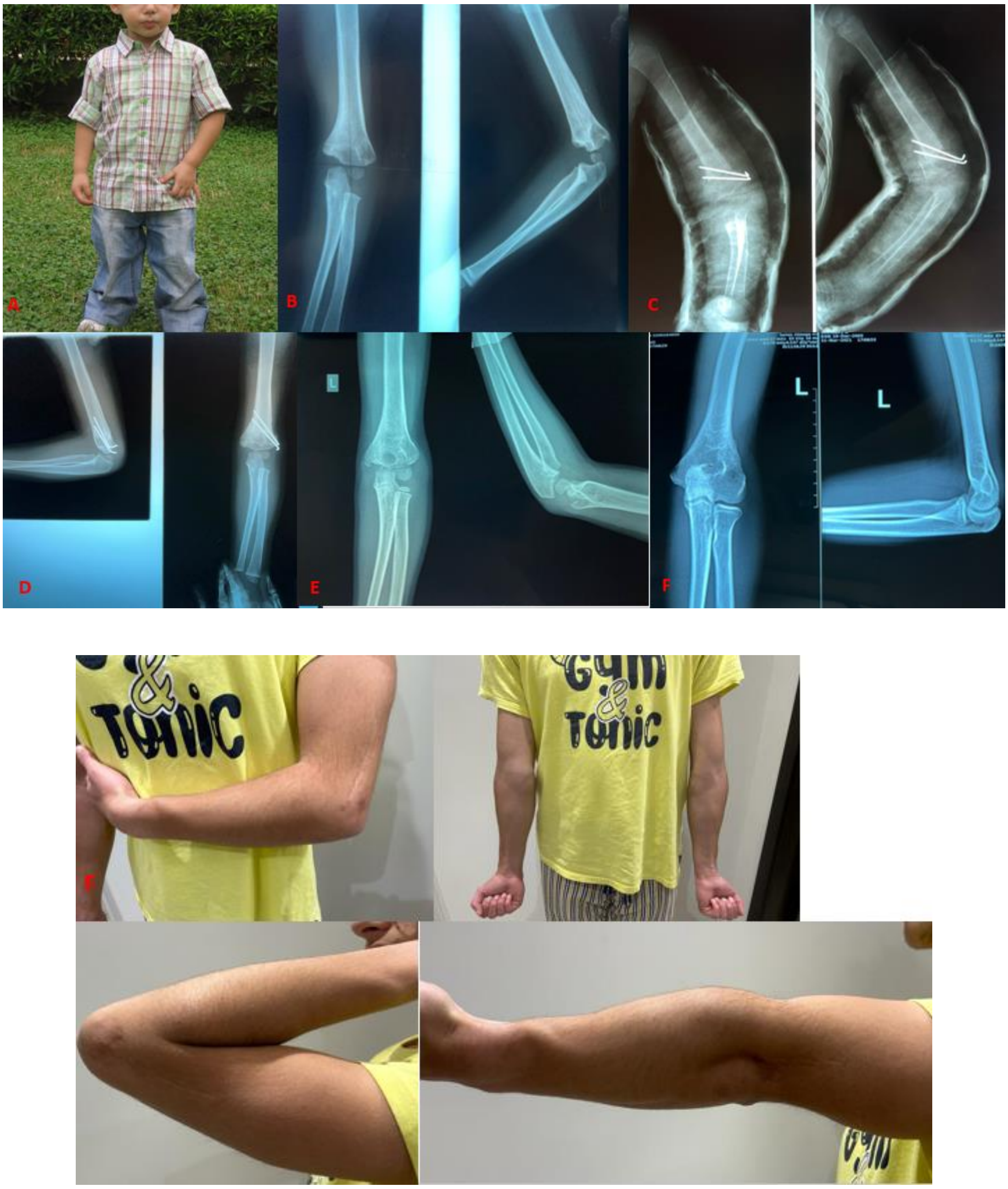

Figure 4: Clinical case of a 3 year old patient who presented to the clinic for cubitus varus of 20°. A: Preoperative clinical photo of the deformed left elbow. B: Preoperative X-ray of the left elbow. C: 6 weeks post-operative X-ray of the left elbow just before cast removal. D: X-ray of the left elbow 6 months post-op just before k wire removal. E: X-ray of the left elbow 3 years post-op. F: X-ray of the left elbow 13 years post-op. G: Clinical photos 13 years post-op showing a restored flexion, extension with a radiological carrying angle of 3° of valgus and the surgical scar

Figure 5: Clinical case of a 3 year old patient who presented to the clinic for cubitus varus of 18°. A: Preoperative clinical photo of the deformed left elbow with debilitating internal rotation. B: Preoperative X-ray of the left elbow. C: 6 weeks post-operative X-ray of the left elbow before cast removal. D: X-ray of the left elbow 6 months after k wires and 8 plate removal. E: X-ray of the left elbow 6 years post-op. F: Clinical photos 6 years post op showing a restored flexion, extension with a radiological carrying angle of 5° of valgus and the surgical scar

It is important to mention the statistically significant difference of sex and age between both groups ($p = 0.04$).

Total major complications were similarly observed in both groups ($p = 0.237$).

Total minor complications were more frequent in Group A (45, 90% of total complications) than Group B (39, 92.9% of total complications), yet no statistical significance is observed ($p = 0.422$).

If we evaluate every minor complication apart, no statistically significant result is shown when comparing the values for group A and B. However, group A had more hypertrophic scar events [14 (73.7%) patients] than group B [9 (31%) patients] ($p = 0.004$).

No significant statistical difference concerning preoperative range of motion and carrying angle is seen between both groups (p value not shown), therefore, preoperative severity regarding flexion, extension and varus carrying angle is homogenous in group A and B.

Concerning post-operative active flexion, extension and clinical/radiological carrying angle, no significant statistical differences between both groups ($p > 0.05$).

Gain of flexion in group A is 18.5°; 3 (15.8%) patients experienced mean loss of 8° of flexion. In Group B, gain of active flexion is 14.5°, 4 (13.8%) patients lost a mean of 4° in active flexion. No statistical difference is seen between both groups regarding gain or loss of flexion ($p = 0.852$, $p = 0.754$, respectively).

Overall recurvatum reduction in both groups was observed which lead to the low gain value of active extension (0.8° vs 1.2°). No statistically significant difference was observed in both groups ($p = 0.831$).

No statistically significant difference is seen regarding the clinical carrying angle ($p = 0.894$), and the radiological carrying angle ($p = 0.747$) in both groups. Therefore, group A and B subjects experienced comparable improvements.

Excellent clinical results were found to be comparable between group A and B ($p = 0.766$). The same goes for clinical results classified as good ($p = 0.923$) and poor ($p = 0.212$).

Our data showed that group B patients were more pleased with the overall appearance of their post-operative elbow versus group A patient. In fact, 84.2 % of patients in group A showed satisfaction compared with 93.1% of patients in group B, a statistically significant result ($p < 0.0001$). On the other hand, overall patient dissatisfaction was comparable between the two groups (15.8% vs 6.9%) ($p = 0.324$).

Table 6: Comparison of variables between group A (K-wire construct) and group B (K-wire + 8-plate/Blount Staple construct). Statistically significant results are outlined in bold. The population compared is heterogeneous vis-à-vis sex and age; the occurrence of hypertrophic scars is less prominent in group B and overall patient satisfaction is more pronounced. Complication rate, range of motion and clinical results are similar between both groups

Variables	**Group A**	**Group B**	***p-value***
Male	9	22	_
Female	10	7	_
Total	19 (39.6%)	29 (60.4%)	***p = 0.04***
Mean Age (years)	18.2	15.2	***p = 0.04***
Radial Neuropathy (% of total patients/group)	2 (10.5%)	0	*p = 0.074*
Median Neuropathy (% of total patients/group)	0	0	_
Ulnar Neuropathy (% of total patients/group)	0	1 (3.4%)	*p = 0.413*
Residual Varus (% of total patients/group)	3 (15.8%)	2 (6.9%)	*p = 0.324*
Osteomyelitis (% of total patients/group)	0	0	_
Iatrogenic Epiphysiodeses (% of total patients/group)	0	0	_
Hardware Failure/Nonunion (% of total patients/group)	0	0	_
Vascular Injury (% of total patients/group)	0	0	_
Hypertrophic Scar (% of total patients/group)	14 (73.7%)	9 (31%)	***p = 0.004***
Edema (% of total patients/group)	12 (63.1%)	16 (55.1%)	*p = 0.583*
Surgical Site Infection (% of total patients/group)	5 (26.3%)	4 (13.8%)	*p = 0.277*
Lateral Condyle Prominence (% of total patients/group)	4 (21%)	2 (6.9%)	*p = 0.147*
Carrying Angle < 5° of Valgus (% of total patients/group)	10 (52.6%)	8 (27.6%)	*p = 0.08*
Total Complications	50	42	*p = 0.541*
Minor Complications (% of total complications)	45 (90%)	39 (92.9%)	*p = 0.422*
Major Complications (% of total complications)	5 (10%)	3 (7.1%)	*p = 0.237*
Nerve Palsies (% of total patients/group)	2 (10.5%)	1 (3.4%)	*p = 0.614*
Nerve Palsies Unresolved (%)	0	0	_
Mean Post-Op Flexion	150.6°	147.2°	*> 0.05*
Mean Post-Op Extension	-7°	-5°	*> 0.05*
Mean Post-Op Clinical Carrying Angle	5.6°	6.1°	*> 0.05*
Mean Post-Op Radiological carrying Angle	6.4°	7.5°	*> 0.05*
Mean Gain of Flexion	18.5°	14.5°	*0.852*
Mean Gain of Extension	0.8°	1.2°	*0.831*
Mean Gain of Clinical Carrying Angle	22.1°	21.9°	*0.894*
Mean Gain of Radiological Carrying Angle	23.9°	25.7°	*0.747*
Excellent Clinical Results (n/%)	13/68.4%	21/72.4%	*p = 0.766*
Good Clinical Results (n/%)	5/26.3%	8/27.6%	*p = 0.923*

Poor Clinical Results (n/%)	1/5.2%	0	*p = 0.212*
Overall Patient Satisfaction (n/%)	16/84.2%	27/93.1%	***p < 0.0001***
Overall Patient Dissatisfaction (n/%)	3/15.8%	2/6.9%	*p = 0.324*

4. Discussion

4.1. Lateral Closing Wedge Osteotomy

The lateral closing wedge osteotomy's main drawback is the prominence of the lateral condyle usually causing the operated joint to look different from the unaffected side with a matching carrying angle [16]. However, performing the procedure before the age of 11, as done in 87.5% of patients in this study, reduces lateral condyle prominence. Lee and his colleagues showed that one of the reasons for prominence besides the severity of cubitus varus was the age of operation. In fact, the mean change of prominence amount in children less than 11 years old (36.6%) was significantly greater than the mean change in lateral condyle prominence amount in children aged 12 years or more (20.4%), (p = 0.001) [17]. Classically, this procedure conserves a medial hinge and therefore, does not allow the translation of distal humerus [16]. However, Devnani's technique, adopted in our institution, was modified in a way that the osteotomy reached the ulnar cortex in order first to allow a more flexible translation, and second, to prevent the rotation of the distal fragment over an intact medial osteoperiosteal hinge [10,18]. This increases the rotational stability of the osteotomy site. The risk of lateral condyle prominence is also reduced by medial translation of the distal fragment until lateral cortices were aligned [10]. In fact, only 12.5% of patients in our study suffered from lateral prominence, compared with values ranging from 22% [19] to 63% [20] in literature. 3D templating techniques showed an increased osteotomy accuracy but lacked significant aesthetic and functional results compared to the conventional LCWO with an additional operating time, cost and preparation [21]. No matter the surgical technique, or fixation method, when adequately employed, satisfactory outcomes with minimal complications were achieved. "Excellent" and "good" were the dominating long-term results [22,23,24]. Bone remodeling basically corrected hyperextension deformity in children ≤ 10 years old, and internal rotation was well tolerated as it is easily compensated by shoulder rotation [24]. A simple LCWO focusing on varus correction was therefore sufficient. However, we also preferred to correct hyperextension and internal rotation to address the deformity completely. More complicated osteotomies risked loss of correction because derotation reduced bony contact as was stated by Tagaki [25].

4.2. Fixation methods:

Fixation method is crucial to maintain the stability of the osteotomy site and minimize loss of correction. A wide variety and combination of internal/external fixation methods can be employed with variable rates of success, advantages and complications [26, 27, 28, 29, 30]. However, few studies compare these fixation methods and focus instead on the type of osteotomy performed in order to prevent the lateral condylar prominence. Closed reduction of deformity and long-arm cast application provided an unreliable hold on the distal fragment jeopardizing stability and increasing the risk of Volkman Syndrome [19]. Rang in 1974 reported that 3 out of 8 patients treated with cast met failure and required secondary correction [31]. Isolated lateral K-wires can be employed but do not seem to provide a stable construct [18] and can give rise to many complications including pintract infection, pin loosening, and therefore, loss of correction [19]. Crossed wires did not offer any significant advantage regarding stability and complications as stated by Sweeney (1975) [32]. In an attempt to increases montage stability, French method consisted of holding the osteotomy site with 2 screws and a figure-of-8 wire loop. A more stable construct with better functional outcomes were provided by this montage. Yet, in 3 patients, the wire loop slipped from the screw's head leading to a postoperative correction loss [33]. Compared with k-wires, external fixation achieves better functional and cosmetic outcomes, having a significantly better carrying angle correction with a shorter learning curve [34], an interesting method, yet we preferred not to employ it in our institution for many reasons: the low socioeconomic status of the majority of patients proved them to be minimally compliant with pin dressing protocols, the culture that views a child with an external device at the elbow as unacceptable, embarrassing and unsightly and finally the much higher cost of external fixator which discouraged patients to perform the surgery in a medical system that provides no financial coverage. Moreover, an increasing number of studies showed good and excellent results with lateral plating Reference [8,9,10,11,12,13].

In our institution, we preferred to augment the k-wire construct using an 8-plate or a Blount staple acting as an alternative to 8-plate. We usually employ 8-plates in distal femur, proximal tibia lateral or medial hemiepiphysiodeses, or as buttress plating for autografts in calcaneal lengthening procedures. Instead of applying the definitely effective yet bulky plates such as distal humeral LCP plates, or simply K-wires, we opted to randomly assign two groups of patients with an augmented k wire construct using an 8-plate or Blount staple, and K-wires. The idea was to prove the biomechanical superiority of an augmented K-wire construct compared to a non-augmented montage. Kalaci in 2009 compared K-wire fixation and Y plate fixation in 16 soldiers suffering from cubitus varus. 3 cases in the K-wire group, and 1 case in the Y plate fixation group had poor results. The study concluded that Y plates in adults provide rigid fixation and allow early active motion minimizing possible complications related to implant failure [35]. These results might be extended to the paediatric population. Persiani in 2017 provided a smaller sample of patients consisting of 15 child, 8 of which receiving an angular plate with screws, and seven receiving 4 k-wires. Statistical analysis showed better functional outcomes in the group treated with angular plate, with a significantly better correction of the HEW angle, lesser lateral prominence index, and higher patient satisfaction [2].

4.3. Complication rates

We attempted to analyze the results (including complication rates, functional outcomes and range of motion) despite the heterogeneous distribution of age and sex between both groups. (p=0.04).

In the largest published series of complications with humeral osteotomy for posttraumatic cubitus varus, Raney reported a higher rate of return to surgery for loss of reduction with K-wires fixation. On the other hand, locking plate fixation technique and pin fixation techniques resulted in overall low complications (nerve palsies, loss of flexion, lateral prominence, growth arrest, unsatisfactory scar, under-correction, osteomyelitis) similar to the rates reported in our study, but when opting for the posterior triceps-splitting approach, higher incidences of nerve palsies were reported versus none with the lateral triceps-sparing approach [8]. Triceps-sparing lateral approach is unanimously employed for all patients in our institution, minimizing therefore nerve palsies attributed to the approach. No significantly statistical difference was seen concerning the minor or major complications described above between the two fixation methods which leads us back to Raney postulating the comparable rate of complications. However, an unsightly hypertrophic scar was observed more in group A ($p = 0.004$). With attention to the anatomic pathways of nerves and increased awareness of the mechanics of the osteotomy, most of these complications are avoidable. In fact, minimizing proximal exposure of humerus protects the radial nerve which courses down the posterior aspect of the humerus between the medial and lateral head of the triceps proximally, and then pierces the lateral intermuscular septum and runs between the brachialis and brachioradialis distally [36]. Careful retraction helps preserve the integrity of the ulnar nerve. Lateral condylar prominence index was calculated for each individual patient (values not shown), by measuring the amount of bone lateral to the axis of humeral shaft compared with the width of distal humerus [20]. The technique implemented in our institution consisted of medially translating the completely osteotomized distal humerus until the lateral cortices of the distal and proximal fragments are perfectly overlapping. Destabilizing the medial cortex at the cost of minimizing the prominence of the lateral condyle was believed to be counteracted by augmenting the classic k-wire construct with a plate or staple. However, both fixation methods yielded comparable results as of the lateral condylar prominence index with no hardware failure occurring in any of the groups.

4.4. Overall surgical outcomes and patient satisfaction

Despite excellent and good results occurring in both groups, ($p = 0.766$ and $p = 0.923$ respectively), overall patient satisfaction on the long-term was more pronounced in the augmented construct group ($p < 0.0001$). In our study, complication rates are low, and therefore augmenting a k-wire construct is not associated with lesser post-operative complications.

Only one patient in the K wire construct group had poor results because of non-compliance.

4.5. Timing of surgery and construct choice vis-à-vis skeletal maturity

Skeletally immature children have an outstanding bone remodeling potential, which will deemphasize the lateral aspect of the distal humerus. Muscle strength, function and mass surrounding the lateral condyle will also help to mask its prominence [38]. However, an established varus deformity does not correct with time regardless of skeletal maturity [39]. Amidst the conflicting data and controversy regarding the time of surgery, in the absence of initial physeal injury, we prefer performing the corrective osteotomy before the age 11, hence, before skeletal maturity, in order to minimize lateral condylar prominence. In our study, a total of 6 patients had a prominent lateral condyle, 4 (21%) in group A, versus 2 (6.9%) in group B all of which presented at a follow-up before the age of 11. After skeletal maturity, it would be interesting to calculate and compare the lateral condylar prominence index and to observe the effect of bone remodeling in these patients.

Implementing more rigid fixation such as an augmented K-wire construct might be more interesting in skeletally mature patients especially in the absence of an intact medial cortex.

This might lead us to think that skeletally immature patients will equally benefit from an augmented or a regular construct (K-wires), and older children should systematically receive a more robust montage. However, our study did not compare clinical results before and after skeletal maturity concerning fixation methods. Therefore, the exclusive use of an augmented montage in older patients and the versatility of choice of construct in younger children is yet to be recommended.

4.6. Range of motion and bone remodeling

In our study, supracondylar valgisation osteotomy significantly improves long-term active elbow flexion ($p < 0.0001$) to a comparable yet lesser angular value of the contralateral side ($p = 0.005$). In fact, mean active flexion gain is 16°. Verka and his colleagues in their series of 25 patients operated on SCO using a percutaneous dome osteotomy, 44% reported gain in range of motion and 40% reported no loss or gain in range of motion. However, 16% have experienced loss of their motion arc [16]. These range of motion results were comparable to the results procured by the classic LCWO in literature [24]. In our study, only 7 patients (14.6%) have experienced loss of active post-operative flexion, 3 (6.2%) of which were operated using Kirschner wires, and 4 (8.3%) using 8 plate and kirschner wires. 6° is the mean loss in these patients. Type of fixation did not affect flexion loss since the results did not differ between the 2 groups ($p = 0.754$). This leads us to suggest that the problem is mainly technical regardless of fixation method, and failure to adequately correct hyperextension at the osteotomy site in these patients might be the reason behind this diminished flexion post-op. This loss of flexion however was not perceived and did not affect patients' daily activities. 1 patient from Group A participating in recreational boxing with a post-operative active loss of flexion of 7° performed with no pain and no discomfort. The lack of professional or athletic patients in this study makes it hard to draw a certain conclusion regarding the effect of surgery on high level activity soliciting arm flexion.

Active extension improvement was not statistically significant ($p = 0.533$). However, we have observed a reduction of 9° in active extension. This value indicates the restoration of the normal recurvatum range in 23 patients (47.9%), 9 (18.75%) of which were operated using Kirschner wires, and 14 (29.1%) using 8 plate and Kirschner wires. This is due to the correction of the hyperextension during the procedure and the effective remodeling potential in children less than 10 years old [24].

Fixation method did not affect gain of carrying angle, gain of active flexion and active extension all results being statistically non-significant. Mean post-operative flexion, extension, and carrying angle values were also comparable between group A and B.

As Devnani mentioned, "once a varus always a varus" [10]. According to Sharrad [40], an angulatory deformity is more likely to correct when it is in the plane of motion of a hinge joint. Therefore, spontaneous varus deformity correction is difficult and flexion-extension inevitably improves with time. This explains overall improvement of range of motion in the long-term and between the two groups, along with overall satisfaction of most patients with their elbow mobility when specifically asked about, having little or no negative effect on their usual daily activities.

4.7. Surgeon expertise

Surgeon experience definitely has a certain role in minimizing complications and increasing patient satisfaction Reference [21]. In our institution, a single senior surgeon was performing regularly supracondylar valgisation osteotomy for more than 25 years. In fact, with the mastery of surgical anatomy and osteotomy mechanics, most complications are preventable. Increased awareness and experience of surgeons in that matter drastically improves patient's safety and quality of life. In the case of inexperienced surgeon, 3D templating might be an interesting option [21].

4.8. Study limitations

This is a small heterogeneous retrospective descriptive study-level III, a much larger and homogeneous sample size is required to draw more subtle conclusions regarding fixation methods. Clinical assessment of deformity with a goniometer by an observer is subject to error, however, as the same observer carried out all the measurements, the effect of this error is probably insignificant. Demographic variables such as sex and age are significantly different. This should be considered as an analysis bias. Radiological data were also subject to measurement bias during our study. Another weak point in this study is that data were not analyzed according to patients' skeletal maturity which leaves us with some important unanswered questions such as: Should an augmented construct be applied systematically for all patients regardless of age?

5. Conclusion

Cubitus varus is the most common long-term complication after supracondylar paediatric elbow fracture. Children are often embarrassed of their "misshapen arm", self-aware and even socially rejected. The unsightly and deformed elbow therefore constitutes the main reason of consultation.

This is a small heterogeneous cross-sectional descriptive study of 48 patients operated by the same senior surgeon, utilizing the same surgical technique and approach, while randomly assigning each individual with a different fixation method.

The osteotomy method opted in our study no matter the montage employed yielded comparable and excellent/good results with few complications. Comparing skeletally mature and skeletally immature patients on a much larger scale in a future study might give us an insight over which fixation method is more suitable.

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