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ORIGINAL STUDY

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Pediatric distal humeral supracondylar fracture – achievement of optimal pinning configuration

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Pediatric supracondylar humeral fracture is commonly managed using closed reduction and percutaneous Kirschner wires pinning. However, there is no consensus on optimal pinning configuration in the literature. Our study aims to review the pinning configuration in our department, correlate our results with the available literature, and suggest the optimal configuration using basic biomechanics principles. We performed a retrospective review on children that were treated with K-wire pinning for supracondylar fracture at our institution between August 2017 and August 2019. Intra-operative antero-posterior view fluoroscopic images were used to measure the pin separation ratio (PSR), pin crossing angle (PCA), medial inclination angle (MIA) and lateral inclination angle (LIA). Pearson Correlation was used to identify the relationship between the variables. Ninety-one patients were included for analysis (39 male: 52 female), with a mean age of 6. Average PCA in the crossed pin and lateral-entry only technique CA was 75° and 12°, respectively. Mean crossed pin and lateral-entry only technique PSR is 0.54 and 0.17, respectively. There was a significant difference in both mean PSR and PCA between the configurations (p <0.01). In subgroup analysis, optimal PSR > 0.33 and PCA >90° were best achieved in crossed pinning using 1 medial and 2 lateral pins. Assessing the biomechanical characteristics of the different fixation techniques, we have found that 2 lateral divergent pins and 1 medial pin using the crossed pin technique optimized both the PSR and PCA. We would recommend this configuration to optimize the stability of the fixation construct.

Level of Evidence: IV; Case Series

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Keywords: Supracondylar; configuration; pin spread ratio; pediatric; humerus; pin crossing angle.

INTRODUCTION

Supracondylar humeral fracture is the most common elbow fracture in the pediatric population. It has an annual incidence of approximately 180 / 100,000 and accounts for 60-75% of all pediatric elbow fractures *(1,2)*. Children are prone to this fracture due to ligamental laxity and weakness of the metaphyseal ridge between the coronoid fossa and the olecranon fossa. Hyperextension with mechanical loading is the most common mechanism of injury and results in extension type supracondylar fractures, described according to Gartland's classification *(3)*. Flexion type supracondylar fractures, on the other hand, are rare.

Displaced supracondylar humeral fracture are commonly managed with open or closed reduction and percutaneous Kirschner wires (K-wire) pin-

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ning. The two most used pin configurations are the lateral-entry only technique and the crossed pin technique. However, the choice of pinning configuration remains controversial and is based primarily on the preference of the surgeon *(4-6)*. The British Orthopaedic Association Standard for Trauma Section 11 (BOAST 11) supports both options. Crossed pinning is advocated for better reduction maintenance, whereas divergent lateral pinning is recommended for the lower risk of ulnar nerve injury *(7)*.

Previous studies and systematic reviews have been conducted to provide clarification on optimal pinning of supracondylar fractures, ranging from biomechanical analysis of configuration *(8-12)*, entry point *(13,14)*, pin size *(11,13,15)*, number of pins *(13,16,17)*, pin separation at the fracture site *(8,18,19)*, and clinical outcome *(4-6,20,21)*. The propensity for children to remodel mild deformities resulting from loss of position *(22,23)* and the frequent use of cast immobilization post fixation *(24)* may allow the use of pin configurations with diminished stability.

A 90° crossing angle between pins improves the construct stiffness stability in line with biomechanical studies of fine wire configuration in ring fixation using the Ilizarov technique *(25,26)*. Although lateral pinning configurations may theoretically achieve similar pin separation at the fracture site, optimization of crossing angle is made difficult by the anatomical limitations imposed by the morphology of the distal humerus. We hypothesized that although idealized pin configurations exist for both crossed pinning and all lateral wire technique, achievement of optimal pin separation at the fracture site and pin crossing angle would be more difficult to achieve with the lateral-entry only technique compared with crossed pin technique.

The aim of the current study was to retrospectively review a cohort of patients who underwent pinning of a supracondylar fracture to assess pin separation at the fracture site and crossing angle comparing crossed pin with lateral-entry only technique. The measured parameters of observed pin configurations were analyzed using basic biomechanics principles to speculate the stability of the fixation.

METHODS

We performed a retrospective review of all pediatric patients undergoing surgical stabilization of a supracondylar fracture at our institution (a major tertiary care trauma center) between August 2017 and August 2019. All patients were treated operatively with open or closed reduction and K-wire pinning with either lateral-entry only or crossed pinning technique by an orthopedic consultant surgeon or orthopedic in-training under supervision. The number of pins and configuration were primarily based on the preference of the operating surgeon at the time of surgery. Intra-operative fluoroscopic images were taken as standard practice. Antero-posterior (AP) view was taken to ensure satisfactory pins entry at distal fragment and coronal trajectory, and lateral view to confirm the sagittal trajectory of the pins.

Fracture displacement was assessed using Gartland's classification based on the AP and lateral plain radiographs at initial presentation. Intra-operative AP view fluoroscopic images were used for each patient to measure the pin separation ratio (PSR) and pin placement angle. A PSR parameter was defined as below to quantify the pin separation at the fracture site independent of fracture location and distal humerus size to enable comparison between different patients (Figure 1a). In cases where more than two pins were used, the maximum pin separation distance at the fracture site for the outer most pin was used.

$$\textit{Pin seperation ratio (PSR)} = \frac{\textit{Pin seperation distance at the fracture site (mm)}}{\textit{Width of humerus at fracture site (mm)}}$$

Three parameters were defined to characterize the angulation of the wires in the coronal plane. The medial inclination angle (MIA) defined the angle of inclination of the medial wire in the coronal plane referencing a perpendicular line to the long axis of the humerus. This reference point was selected as being most independent of rotation or flexion of the humerus away from the standardized orthogonal planes on the AP radiograph. The lateral inclination angle (LIA) was similarly measured for the lateral pin. When more than one pin was used on either the

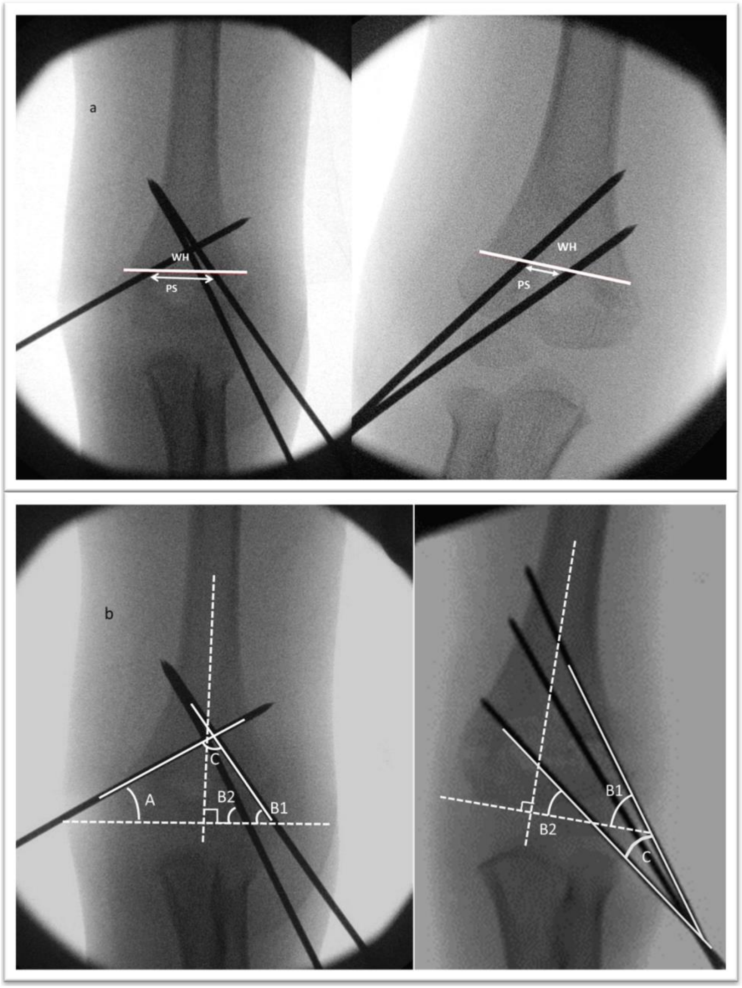

Figure 1. — Pin Separation Ratio (PSR), Pin Crossing Angle (PCA) and Pins Inclination Angle Measurements. (a) Pin Separation Ratio; Straight line = Width of humerus at fracture site (WH); Arrow line = maximum pin spread distance at fracture site (PS). PSR = PS/WH. (b) Pin Crossing Angle and Inclination Angle; Dotted line = perpendicular line to the long axis of the humerus; A = medial inclination angle (MIA); B1 = Lateral Inclination Angle (LIA) Steep; B2 = LIA Slight; C = Maximum PCA.

lateral or medial side these angles were calculated for individual pins. To differentiate the two pins on the same side they were characterized as “slight” or “steep”. The pin crossing angle (PCA) was measured as the maximum crossing angle between pins irrespective of the number of pins used (Figure 1b); in lateral-entry only, this will be equivalent to the maximum divergent angle.

All statistical analyses were conducted using SPSS software (version 26.0; SPSS Inc., Chicago, II, USA). Descriptive statistics and 95% confidence intervals (CI) were calculated for continuous variables. Chi-Square X^2 and Pearson Correlation was used to identify the relationship between the variables, and unpaired t-test was analyzed between different configurations. A p value of less than 0.05 was deemed significant.

RESULTS

Ninety-one patients were included for analysis (39 male:52 female), with a mean age of 6 (range 1-12). Between Aug 2017-July 2018, thirty-four patients presented to our center with supracondylar humeral fracture; fifty-seven attended between Aug 2018-Aug 2019. 24 cases (26%) were Gartland II fractures, 66 (73%) were Gartland III fractures and 1 (1%) was flexion-type injury. Demographic data are summarized in Table I.

Table II summarized the pins configuration in each fixation methods. Seventy-one patients (78%) underwent crossed pin fixation of which 57 (80%) were Gartland III fractures. There were 13 Gartland II injuries and 1 flexion injury. In 76% of cases (n=54), crossed pinning consisted of a single

Table I. — Patient characteristics for supracondylar humeral fracture

Characteristics	Crossed Pin	Lateral-Entry Only Pin
Total (N, %)	71 (78%)	20 (22%)
Gender (N, %)		
Male	30 (42%)	9 (45%)
Female	41 (58%)	11 (55%)
Age (Mean, Range)	6 (1-12)	6 (2-8)
Gartland's (N, %)		
II	13 (19%)	11 (55%)
III	57 (80%)	9 (45%)
Flexion	1 (1%)	0

medial and a single lateral pins. In 17 cases (24%) 3 pins were used. In crossed pin configuration, the mean pin separation ratio (PSR) was 0.54 (95% CI 0.51-0.57). The range for PSR was 0.00 to 0.83 (Figure 2a and 2b). The mean medial inclination angle (MIA) was 52º (95% CI 50-55) and the mean lateral inclination angle (LIA) for the slight pin was 52º (95% CI 50-55) and 57º (95% CI 53-62) for the steep pin. The mean pin crossing angle (PCA) was 75.3º (95% CI 72.0-78.6). In single-lateral-pin crossed pinning, the mean PSR was 0.55 (95% CI 0.51-0.59) and PCA was 73º (95% CI 69-76). In two-lateral-pin crossed pining, the mean PSR was 0.51 (95% CI 0.46-0.57) and PCA was 83º (95% CI 75-91).

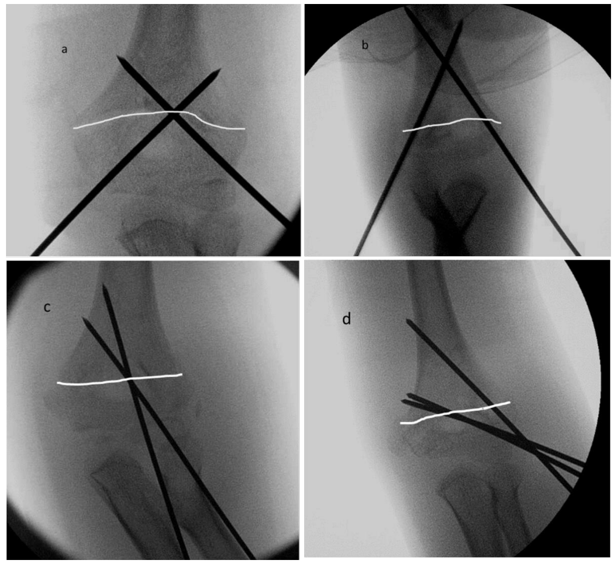

Figure 2. — Example of Pin Separation Ratio (PSR). (a) Crossed Pins PSR of 0.00; (b) Crossed Pins PSR of 0.83; (c) Lateral-Entry Only PSR of 0.00; (d) Lateral-Entry Only PSR of 0.51; White line = fracture line.

Twenty patients (22%) underwent lateral-entry only pin fixation of which majority were Gartland II fractures (n=11, 55%). There were 9 Gartland III. In 85% of cases (n=17), lateral pinning consisted of a two lateral pins. In 3 cases (15%) 3 pins were used. The mean PSR was 0.20 (95% CI 0.14-0.26). The range for PSR was 0.00 to 0.51 (Figure 2c and 2d). The mean LIA for the slight pin was 44º (95% CI 39-48) and 55º (95% CI 51-59) for the

Table II. — Pins configuration characteristics

Characteristics	Crossed Pin			Lateral-Entry Only Pin		
Number of pins (N, %)						
2	56 (79%)			17 (85%)		
3	15 (21%)			3 (15%)		
Angulation of pin						
MIA	52 ± 10			-		
LIA (Slight)	52 ± 10			44 ± 10		
LIA (Steep)	57 ± 9			55 ± 9		
Number of lateral wires	Total	1 wire	2 wires	Total	2 wires	3 wires
PSR (mean ± SD)	0.54 ± 0.14	0.55 ± 0.15	0.51 ± 0.09	0.20 ± 0.13	0.19 ± 0.11	0.24 ± 0.23
PCA° (mean ± SD)	75 ± 14	73 ± 13	83 ± 14	12 ± 10	10 ± 8	24 ± 10

PSR: Pin Separation Ratio; PCA: Pin Crossing Angle; MIA: Medial Inclination Angle; LIA: Lateral Inclination Angle.

steep pin. The mean PCA was 12º (95% CI 8-17). In two-lateral-pin configuration, the mean PSR was 0.19 (95% CI 0.13-0.25) and PCA was 10º (95% CI 6-14). In three-lateral-pin configuration, the mean PSR was 0.24 (95% CI -0.34-0.82) and PCA was 24º (95% CI 0-48).

We wished to determine the relationship between pin entry angle and PCA on one hand and the PSR on the other for each of the fixation groups – crossed pinning and lateral-entry only technique. In the crossed pinning group, there was an inverse correlation between the PSR and the PCA (R = -0.42, p = <0.01) suggesting that an achieving an increase in the pin separation ratio is offset by a reduction in the pin crossing angle. In the lateral-entry only group, on the other hand, we found that PSR similarly had a negative association with PCA, but this was not found to be significant (R = -0.15, p = 0.52,). The inclination angle of the pins (LIA and MIA) were both significantly correlated with PSR and PCA in crossed pin configuration. As the pin entry angle becomes steeper in LIA and MIA, the PSR increases (significant positive correlation p <0.05); however, this led to reduction in PCA (significant negative correlation p <0.05). In the lateral-entry only group, the negative correlation between LIA with slight angle against PCA was significant (p=0.02). The negative correlation between LIA steep and LIA slight with PSR were not significant (p >0.05).

Comparing the two main pin configuration groups of crossed pinning and lateral-entry only pinning, there was a statistically significant difference in both the mean PSR (0.54 vs 0.20 respectively, p <0.01, 95% CI 0.27-0.41) and the mean PCA (75º vs 12º respectively, p <0.01, 95% CI 56º-70º). Within the crossed pin group, there was a statistically significant difference in the PCA when comparing two lateral pins with one lateral pin (83º vs 73º respectively, p = 0.01, 95% CI -18º- -2º). However, there was no significant difference when comparing the PSR between these two subgroups (p = 0.08, 95% CI -0.05-0.11). Comparing the subgroups of 2 wires with 3 wires in the lateral-entry only technique demonstrated a significant difference in the PCA (10º vs 24º, p = 0.02, 95% CI -25º- -3º) but not in PSR (0.19 vs 0.24, p = 0.56, 95% CI-0.22-0.13).

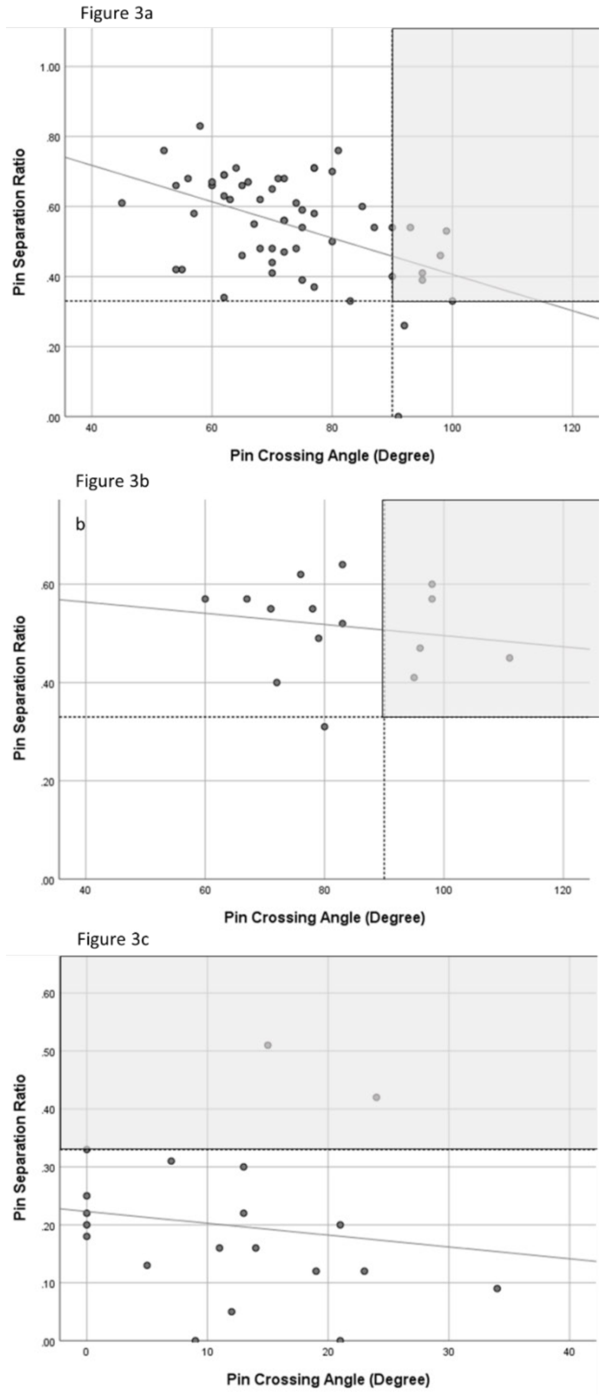

Figure 3. — The relationship between PCA and PSR in Difference Pins Configuration. (a) 1 Medial 1 Lateral Crossed Pin; (b) 1 Medial 2 Lateral Crossed Pins; (c) Lateral-Entry Only Pins. X-axis Reference Line = 90 degrees; Y-Axis Reference Line = 0.33; Shaded Quadrant = Optimal Pin Configuration. Please note recommendation was not achievable in lateral-entry only pin configuration.

Table III. — Number of cases achieving Pin Separation Ratio > 0.33 and Pin Crossing Angle >90º in Different Pin Configuration Groups

	Number of cases in all lateral group (% of total)	Number of cases in crossed pin group (1 medial, 1 lateral) (% of total)	Number of cases in crossed pin group (1 medial, 2 lateral) (% of total)
No of cases where PSR ≥0.33	3/20 (15%)	54/56 (96%)	14/15 (93%)
No of cases where PCA≥90º	0 (0%)	10/56 (18%)	5/15 (33%)
No of cases where both PSR ≥0.5 and PCA ≥90º	0 (0%)	8/56 (14%)	5/15 (33%)

PSR: Pin Separation Ratio; PCA: Pin Crossing Angle.

We then analyzed the scatter plots for each group to determine the spread of achievable values for the PSR and PCA for each of the techniques (Figure 3). We were interested to determine what proportion of patients in each group where a pin separation ration greater than 0.33 and a pin crossing angle greater than 90º was achieved. The results are shown in Table III. In the lateral-entry only group, a PCA greater than 90º was not achieved in any of the observed cases and there were only three cases where the PSR exceeded 0.33 (15%). The scatter plot suggested that both parameters were effectively constrained within a narrow interval of a pin crossing angle between 0 and 30 degrees reflecting the limitations imposed by the available spectrum of entry points and distal humeral morphology for lateral-entry only pin placement. In the crossed pin group, the proportion of patients achieving either a PSR greater than 0.33 or PCA greater than 90º was higher in the 2 lateral wires group (14 of 15 and 5 of 15, respectively) compared with the 1 lateral wires group (54 of 56 and 10 of 56, respectively). The trend in the scatter plot for 1 medial and 1 lateral wire supports a reduction in the pin crossing angle as the pin separation ratio decreases.

In our study cohort, we had 6 cases presented with pre-operatively median nerve palsy, of which 1 progressed into median neuroma due to extend of the initial open injury. There was no iatrogenic ulnar nerve injury reported. There were 30 cases deemed radiologically malunion in their serial radiograph, of which 67% (20/30) were malunited in slight extension. 2 out of the 30 malunion cases had anatomically reduction during intra-operative imaging; 1 was fixed with lateral-entry only technique while another was fixed with crossed wire technique.

DISCUSSION

Supracondylar humeral fractures are common in the child population and the gold standard for displaced fractures is close reduction with percutaneous pinning *(24)*. The treatment goals are to regain anatomical alignment, adequate stability, and prevent post-operative deformity. The exact pin configuration remains controversial in the literature. The crossed pin technique was traditionally the choice of fixation in the 20th century until there became an increased concern of iatrogenic ulnar nerve injury. Skaggs et al. 2004 described the divergent lateral entry pinning technique in supracondylar humeral fracture and had shown good clinical outcome *(27)*. This had led to a renewed interest in lateral entry pinning. However, concerns regarding stability with a lateral-entry only technique in rotationally unstable fractures has prompted some authors to advocate on table tests of stability following lateral wiring to determine if a supplemental medial wire is required *(28)*.

Pinning fixation of supracondylar humeral fracture forms the shape of triangle, with the line connecting the traversal points of the wires across the fracture site forming the base, and both pins as legs. A triangle shape is known to be the most stable construct and is used widely in day-to-day construct in our lives. Different properties must be considered to provide optimal resistance against different deforming forces – bending, translation and torsional force. The wider the pins spread at the

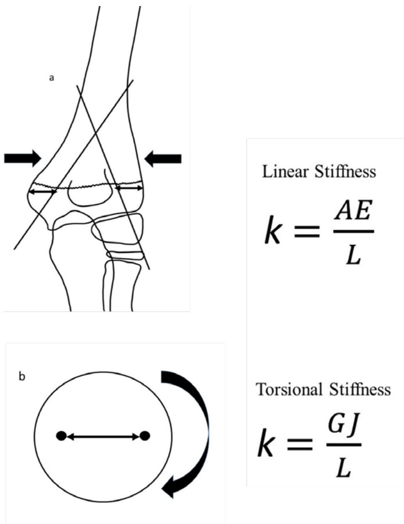

Figure 4. — Rigidity of pinning fixation against different force at fracture site. a) Translational force; b) Torsional force; Arrow = direction of force; Line = length of working distance; k = stiffness, E = elastic modulus, A = cross-sectional area; L = length of working distance; G = rigidity constant, J = torsion constant.

fracture site, the wider the base of a triangle, and the more stable a shape to resist against the coronal plane acting forces of translation, varus, and valgus force (Figure 4a). As the pins spread distance increases, the greater the diameter for circular motion at the fracture site, the stiffer the construct resist against torsional force (Figure 4b). In our result, there is a negative correlation between PCA with the PSR – which means the wider the angle, the smaller the PSR. The reason behind this is, as the PCA becomes wider, the point where the pins intersect becomes closer to the fracture site with the assumption of pin entry point remaining static. Increasing the PCA whilst improving the torsional and coronal plane bending stiffness of the construct, brings the wire crossing point closer to the fracture site. Pins crossing at a fracture site increases the L values (working length) leading to reduction of stiffness (stiffness k is inversely proportionate to working length L). This permits torsion and bending to occur at the fracture site through little force application.

It is unspoken that the pins should not cross at the fracture site as this will give no stability benefit to the fixation. Yet, the value of PSR remains controversial in the literature. Aarons et al. used Baumann's angle to examine 46 crossing pin and 57 lateral entry only pin case PSRs concerning fixation loss. They concluded that there was no association between the variables *(18)*. On the other hand, Pennock et al. reviewed 192 patients and reported that PSR is an important factor in maintaining reduction. They had suggested targeting pin spacing of at least 13mm or 1/3 width of the humerus at the level of fracture *(19)*. Reisoglu et al. included 87 patients retrospectively and found no statistical significance in their cohort; however, their cohort of pin separation distance was >12mm and ratio of 35% on average *(8)*. Along with other literature, they agreed that pin separation ratio is an important biomechanical factor to aid the stability of the construct along with other factors *(14,29)*.

Regarding biomechanical stability of different pin configurations, multiple literatures had reported that three crossed pins have the optimal stiffness against all directional forces, followed by two crossed pins and two lateral divergent pins, lastly parallel and convergent pins, respectively *(9-12,30)*. Zionts et al. demonstrated that crossed pin configuration provides the most resistant torsional force *(10)*. Liu et al. and Li et al. also reported that three crossed pins technique provided the most optimal stiffness combination against translational and torsional forces regardless of fracture characteristics *(9,30)*. In our cohort, 5% of lateral-entry only technique (1 of 20) subjected to re-displacement at follow-up, while only 1% of crossed pin technique (1 of 71) loss reduction. Even though lateral divergent pins may provide adequate stiffness in the clinical setting, clinician should aim to achieve optimal stiffness with crossed pins technique to minimize the risk of re-displacement, and future research should investigate the potential of early mobilization in such cohort post-operatively.

In circular external fixation constructs using fine wires, a biomechanical study by Roberts et al analyzed the stiffness of transfixion wire crossing angle against different compression-bending direction and torsion *(25)*. In their study, they concluded that wire crossing angle of 90 degrees provides the most superior stiffness against external deformation force – axial, translational, torsional, or bending. This finding has been supported by several further studies *(31-33)*. Pin configurations in supracondylar fractures are subject to similar biomechanical principles. In circular fixation, fine wire configuration across a single ring is subject to achieving maximal divergence in a single axial plane. Similarly, in supracondylar fractures, the anatomy of the distal humerus does not enable significant wire divergence in the sagittal plane.

Therefore, pin placement should maximize pin configuration in the coronal plane. The parameters that need to be optimized are optimal crossing angle (90 degrees), pin separation ratio (>0.33), distance of crossing point from fracture site and capitellar entry for adequate stability in the distal fragment. Based on the current literature we advocate the following pinning configuration which has become the standard in our institution. An initial lateral wire should enter the capitellum and be directed steeply to achieve bicondylar fixation in the medial supracondylar ridge. A further lateral wire is inserted through a different entry point and slightly divergent to the first wire. The stability this configuration affords allows the medial wire to be inserted into the medial epicondyle anteriorly with the elbow in relaxed extension. Optimal trajectory in the lateral cortex can be determined on x-ray but we favor a fairly transverse inclination to achieve bi-cortical fixation just above the fracture site on the lateral supracondylar ridge. This configuration optimizes the pin separation distance between the medial and outer steeper lateral wire. The crossing angle is optimized between the relatively transverse medial wire and the less steep lateral wire. The steeper lateral wire enables a crossing point further from the fracture site rather than the less steep wire (Figure 5).

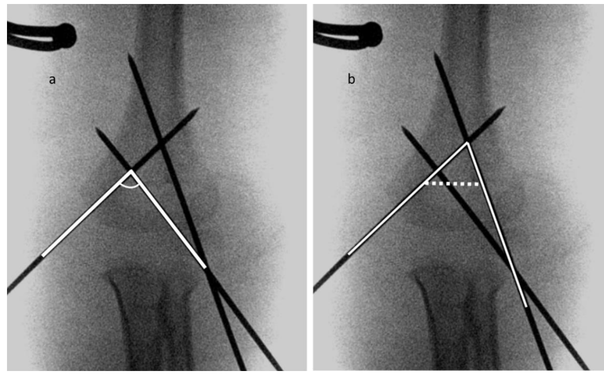

Figure 5. — Crossed Pin Configuration with 1 Medial Pin and 2 Lateral Pins. (a) One lateral pin aim to achieve 90 degrees pin crossing angle with medial pin in slight angle; (b) Second lateral pin aim to achieve >0.33 pin separation ratio with medial pin in steep angle.

To our knowledge, this is the first study that has reviewed the in vivo achieved pin configuration using the biomechanics principle to determine the optimal fixation construct. We felt such analysis permit better clinical correlation. There are a few limitations in the current study. Firstly, we have not considered the stability of the fracture consideration with respect to location and obliquity. However, it would seem pragmatic that an optimized pin configuration should be defined independent of the fracture characteristics as much of the anatomical stabilizing features such as periosteal disruption cannot be reliably assessed on plain radiographs. We have also not investigated loss of position for each of the reviewed fixation constructs and the rate of malunion. Almost all the patient group were discharged following clinical evaluation rather than radiographic assessment. Post-operative x-rays were also found to be taken in oblique rather than standardized orthogonal planes reflecting the practical issues in imaging children's elbows whilst in cast. The current study does not answer the question of what the minimum fixation stiffness is required of the construct to prevent loss of position whilst healing. Therefore, we cannot speculate whether the lateral and crossed pin fixation constructs observed in the current study achieve or exceed this.

The current study has defined an idealized scenario of trying to achieve a pin separation ratio greater than one-third width of the bone at the fracture site and a crossing angle greater than 90 degrees. We have demonstrated that with a single lateral wire in the crossed pin group there is a trade-off between an increasing PSR and a decreasing PCA. Biomechanically which of these parameters should be prioritized for optimization requires further study. However, we have demonstrated that the 2 lateral and 1 medial wire cross pin technique can achieve optimization of both these parameters without this trade off.

CONCLUSION

The current study has investigated the pin configurations in the operative treatment of supracondylar elbow fracture in children which can feasibly be achieved in vivo. Assessing the biomechanical characteristics of the different fixation techniques, we have found that 2 lateral divergent pins and 1 medial pin using crossed pin technique optimized both the pin separation distance and pin crossing angle compared with an all-lateral technique even when three pins are used. We would recommend this configuration to optimize the stability of the fixation construct when fixing them with pinning.

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