

# Comparison of Different Fixation Configurations in Different Types of High Pediatric Supracondylar Humerus Fractures: a Finite Element Analysis

Porovnání různých fixačních konfigurací u různých typů dětských vysokých suprakondylárních zlomenin humeru: analýza metodou konečných prvků

M. BOZOĞLAN<sup>1</sup>, M. KUMBARACI<sup>1</sup>, A. ÖZER<sup>2</sup>, A. TURGUT<sup>1</sup>

<sup>1</sup> University of Health Sciences, İzmir Tepecik Health Research Center, Orthopedics and Traumatology Department, İzmir, Turkey

<sup>2</sup> Yozgat Bozok University, Faculty of Engineering, Mechanical Engineering, Yozgat, Turkey

## ABSTRACT

### PURPOSE OF THE STUDY

The purpose of this study is to compare the stability of different fixation methods in high pediatric supracondylar humerus fractures with a finite element analysis method.

### MATERIAL AND METHODS

Transverse, lateral oblique, and medial oblique fracture models were created in a ten years old boy's distal humerus. Eight different fixation methods were applied to each fracture model. Displacement of the fracture models was measured under the translational and torsional forces.

### RESULTS

In the transverse fracture model; the 6<sup>th</sup> method provided the best stability in internal rotation, external rotation, and extension loading. In varus 7<sup>th</sup> method, valgus 8<sup>th</sup>, and flexion the 5<sup>th</sup> and 2<sup>nd</sup> methods had the best stability. In the lateral oblique fracture model; the 7<sup>th</sup> method had the best stability in all loading directions except flexion and the 6<sup>th</sup> method had the best stability in flexion and had acceptable values in all other directions except valgus and external rotation. In the medial oblique fracture model; the 6<sup>th</sup> method had the best stability in all directions except varus. 3<sup>rd</sup> method was the best fixation type against varus and the second stable fixation type in all other directions.

### CONCLUSIONS

Combining lateral antegrade with lateral retrograde wire and lateral condylomedullary wire provides strong stability in the lateral oblique fracture. Two condylomedullary Kirchner wires and one antegrade lateral wire results in a strong stability in the medial oblique fracture. Medial-lateral condylomedullary and lateral antegrade wires provided the best stability against varus in transverse and lateral oblique fractures.

**Key words:** high pediatric supracondylar humerus fracture, percutaneous fixation method, metaphyseal-diaphyseal junction, finite element analysis.

## INTRODUCTION

The supracondylar humerus fractures (SHFs) that are classically described as fractures through the thin metaphyseal region of the distal humerus without intercondylar involvement are the most common elbow fractures in children (7). Bank et al. described the high supracondylar humerus fractures as fracture planes entering and exiting above the olecranon fossa but within the distal humeral metaphysis (1). Achieving and maintaining an acceptable reduction can be more challenging in metaphyseal-diaphyseal junction (MDJ) fractures because of the limited available cortical bone of the proximal fragment for pin fixation and a higher fracture line (9). Fayssoux et al. defined these types of fractures as metaphyseal-diaphyseal fractures and stated that these fractures are rare but can be problematic in terms of both post-reduction stability and complications such

as reoperations, cubitus varus, pin migration, and prolonged loss of motion (5).

The importance of pin configuration and spread in the management of SHFs are well described before (12). However, there is limited data about high pediatric SHFs in terms of ideal fixation strategy in the literature (6, 14, 15).

The purpose of this study was to compare the stability of various fixation types in three different types of high pediatric SHFs with a finite element analysis (FEA) method. In this way, we aimed to find out the best fixation method for the treatment of these difficult fracture types.

## MATERIAL AND METHODS

### Modeling of fracture and fixation types

After obtaining the ethical committee approval (2022/02-39), a ten-year-old boy's distal humerus digital

images were taken from the hospital's picture archiving and communication system in 3-Dimensional (3D) computed tomography (CT) scans format. The indication of CT scanning was to evaluate an occult fracture of the radial head. A 3D FEA model was created in the Solid Works program (Dassault Systemes, SolidWorks Corp., USA). The metaphyseal-diaphyseal region was defined between two horizontal lines which were drawn proximally where the transverse anteroposterior width of the humerus changed to an increased width in the metaphyseal area proximally and distally tangential to the top of the olecranon fossa (3) (Fig. 1a). Three non-comminuted, reduced fracture model was created in this region with Invesalius (version 3.1) (Centro de Tecnologia da Informaçao Renato Archer (CTI), Brazil). In the transverse fracture model (TM), the fracture line passed through the superior point of the metaphyseal-diaphyseal region (Fig. 1a). In the medial oblique fracture model (MOM), the fracture line started where the transverse fracture line cuts the medial cortex and continues through the lateral cortex by 30° coronally obliquity (Fig. 1b). In the lateral oblique fracture model (LOM), the fracture line started where the transverse fracture line cuts the lateral cortex and exits the medial cortex by 30° coronally obliquity (Fig. 1c). After the fracture models were created, eight different fixation methods (FM) that seven of them with K-wire and one elastic intramedullary nail (EIN) were applied to these models separately by using Solidworks software (Solid Works Corp., MA, USA). The fixation configurations were as follows:

1. Cross pinning with single wire (Fig. 2.1),
2. Medial and lateral condylomedullary fixation (Fig. 2.2),
3. Cross pinning with two lateral and single medial wires (Fig. 2.3),

4. Lateral antegrade and lateral retrograde wires (Fig. 2.4),
5. Antegrade elastic intramedullary fixation with two nails (Fig. 2.5),
6. Lateral antegrade-lateral retrograde-lateral condylomedullary wires (Fig. 2.6),
7. Medial-lateral condylomedullary and lateral antegrade wires (Fig. 2.7),
8. Lateral condylomedullary and lateral antegrade wires (Fig. 2.8).

The prepared solid models were imported to Finite Element Simulation Software ANSYS workbench version 2020R1 (ANSYS Inc., Canonsburg, PA, USA).

### Properties of material and applied forces

All the K-wires that were used in the study were 2.0mm diameter stainless steel and EINs were 3.0mm diameter titanium elastic nails. Material properties for cortical bone Young modulus ( $E$ ) = 16 GigaPascal (GPa), Poisson's ratio ( $\nu$ ) = 0.3, K-wires  $E$  = 200 GPa and  $\nu$  = 0.33, EINs  $E$  = 110 GPa, and  $\nu$  = 0.33 were used as before (3,9,10). In six different directions on three axes (x, y, z) load simulations (internal rotation (IR), external rotation (ER), varus (VaR), valgus (Val), flexion (FL), extension (EX) were applied to each fracture model with each fixation type. The moment of the applied load was ( $M$ ) = 1.5 Newton-meter (N.m) and the magnitude was 10 seconds (Fig. 3).

The contact interfaces with the bone and K-wires were assumed to be the bonded contact. The fracture interface was considered completely broken, and the frictional sliding contact and friction coefficient was taken as 0.2 (3). The proximal part of the humerus model was assumed bonded that not allowed any motion, and forces in all directions were applied to the distal part of the humerus model.

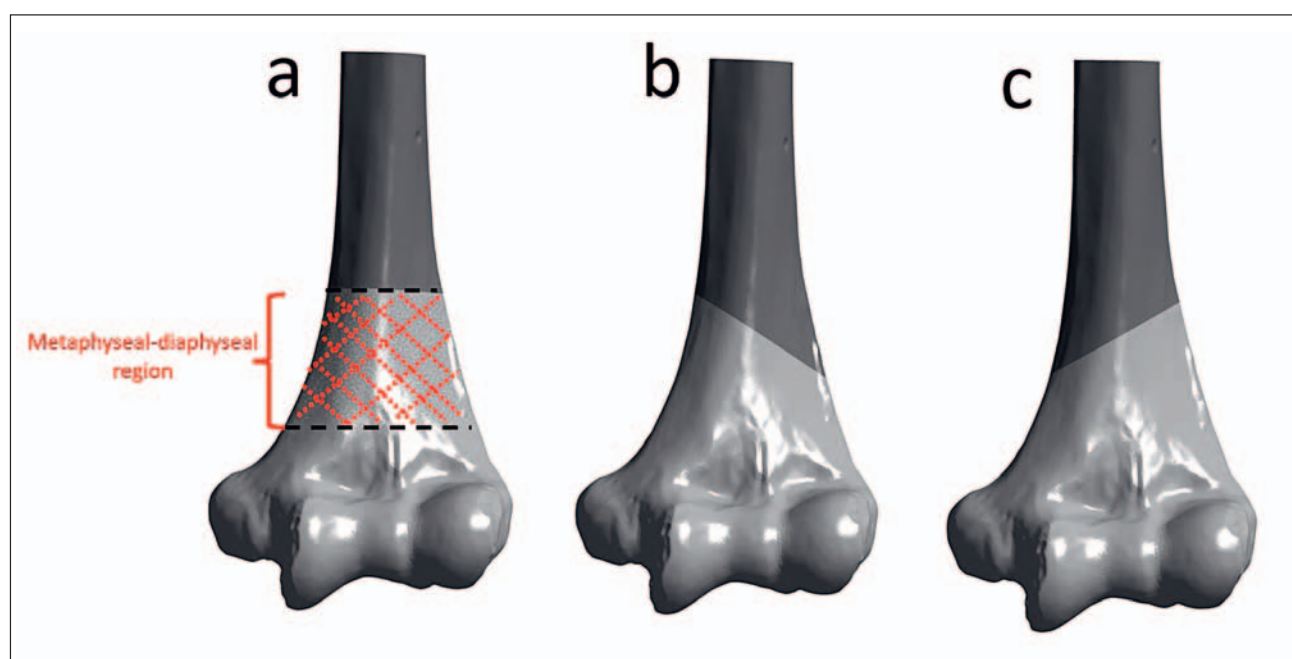


Fig. 1. Illustration of fracture models and metaphyseal-diaphyseal region. Transverse fracture model and metaphyseal-diaphyseal region (a) medial oblique fracture model (b) lateral oblique fracture model (c).

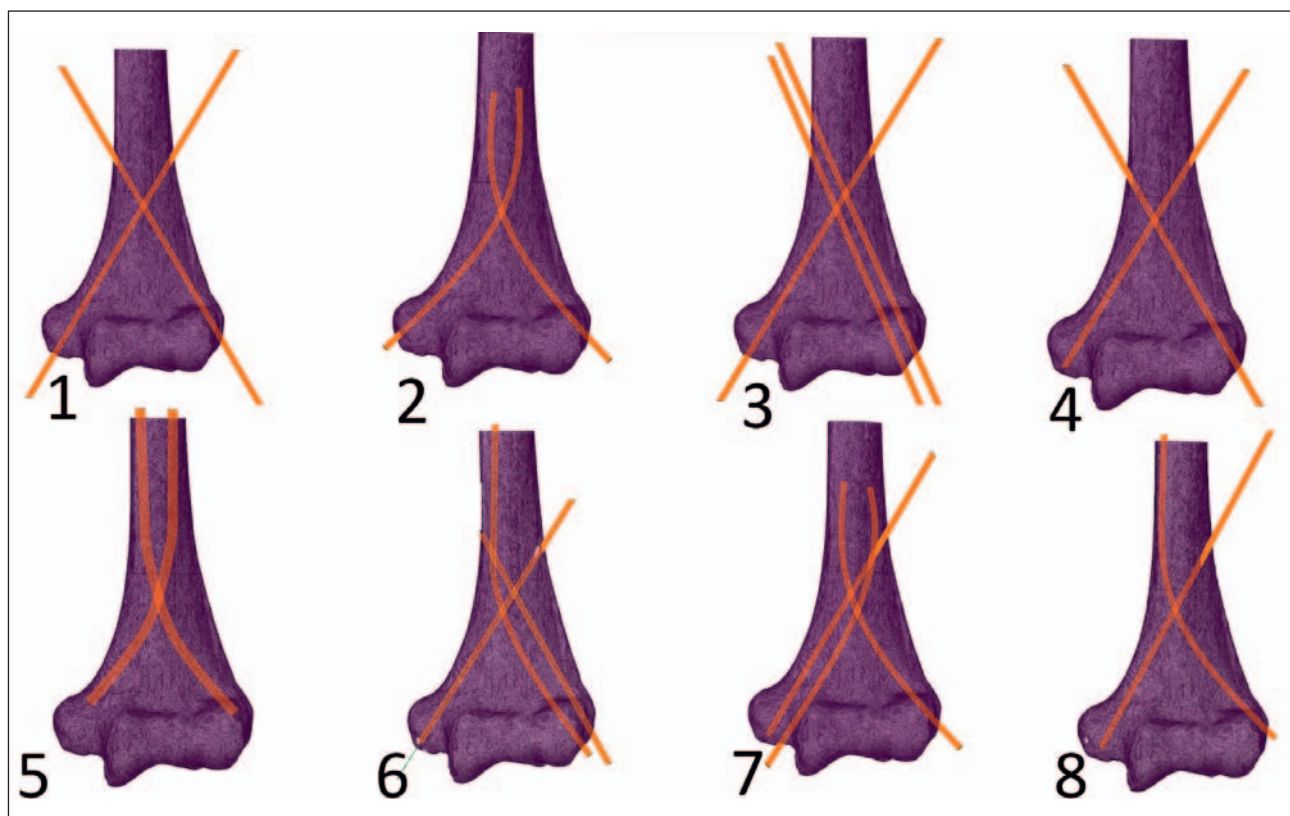


Fig. 2. The fixation configurations. Cross pinning with single wire (1), medial and lateral condylomedullary fixation (2), cross pinning with two lateral and single medial wires (3), lateral antegrade and lateral retrograde wire (4), antegrade elastic intramedullary fixation with two nails (5), lateral antegrade-lateral retrograde-lateral condylomedullary wires (6), medial-lateral condylomedullary and lateral antegrade wires (7), lateral condylomedullary and lateral antegrade wires (8).

### Determination of model's stability

In each fracture model, the distance between the cortices in the opposite direction of the applied load was measured in millimeters (mm) after the load was applied from six different directions for each fixation type. These distances were recorded and compared with each other. The shortest distance that was measured was considered the most stable in each fixation method for the fracture models.

### RESULTS

In the transverse fracture model; FM 6 provided the best stability in internal rotation, external rotation, and extension loading. In varus FM 7, in valgus FM 8, and flexion both FM 5 and FM 2 had the best stability. In both internal rotation and external rotation FM, 8 was the least stable fixation type (Fig. 4) (Table 1).

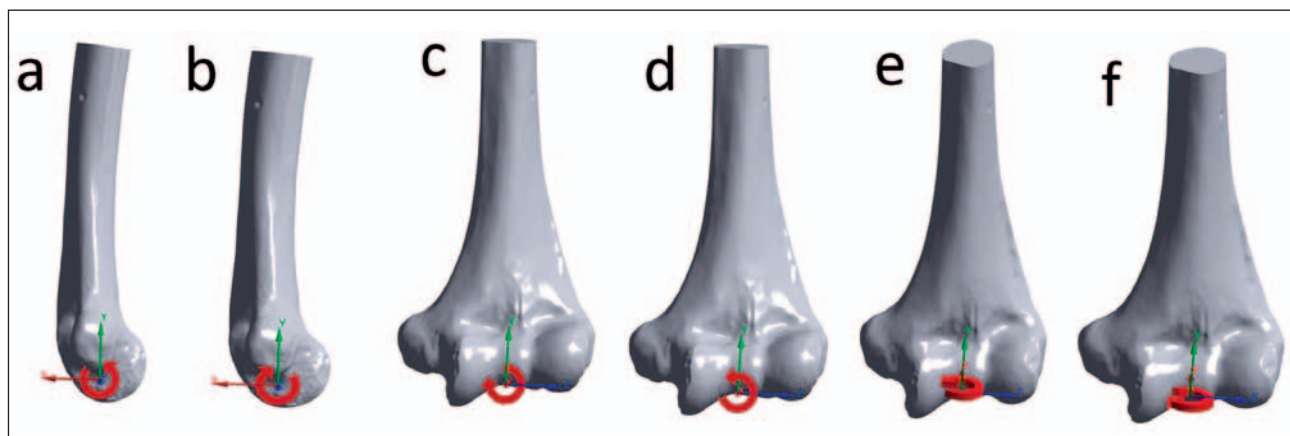


Fig. 3. Illustration of loading simulations. Flexion (a), extension (b), varus (c), valgus (d), external rotation (e), and internal rotation (f).

Table 1. In the transverse fracture model, the distances between the cortices in all loading directions

| Transverse fracture model |                        |                        |                        |                        |                        |                        |                        |                        |
|---------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|
|                           | Fixation method 1 (mm) | Fixation method 2 (mm) | Fixation method 3 (mm) | Fixation method 4 (mm) | Fixation method 5 (mm) | Fixation method 6 (mm) | Fixation method 7 (mm) | Fixation method 8 (mm) |
| Varus                     | 0.0012                 | 0.0006                 | 0.0011                 | 0.0011                 | 0.00096                | 0.001                  | 0.00013                | 0.0003                 |
| Valgus                    | 0.0012                 | 0.0004                 | 0.0003                 | 0.0051                 | 0.00025                | 0.0003                 | 0.00044                | 0.0002                 |
| Flexion                   | 0.001                  | 0.0006                 | 0.001                  | 0.0011                 | 0.0006                 | 0.0015                 | 0.0009                 | 0.0011                 |
| Extension                 | 0.0024                 | 0.0011                 | 0.002                  | 0.0012                 | 0.0016                 | 0.001                  | 0.0013                 | 0.0017                 |
| Internal rotation         | 0.058                  | 0.0415                 | 0.039                  | 0.027                  | 0.0333                 | 0.0254                 | 0.029                  | 0.087                  |
| External rotation         | 0.057                  | 0.0526                 | 0.049                  | 0.041                  | 0.0402                 | 0.025                  | 0.03                   | 0.095                  |

mm: millimeters

Table 2. In the lateral oblique fracture model, the distances between the cortices in all loading directions

| Lateral oblique fracture model |                        |                        |                        |                        |                        |                        |                        |                        |
|--------------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|
|                                | Fixation method 1 (mm) | Fixation method 2 (mm) | Fixation method 3 (mm) | Fixation method 4 (mm) | Fixation method 5 (mm) | Fixation method 6 (mm) | Fixation method 7 (mm) | Fixation method 8 (mm) |
| Varus                          | 0.003                  | 0.006                  | 0.004                  | 0.004                  | 0.005                  | 0.003                  | 0.003                  | 0.006                  |
| Valgus                         | 0.011                  | 0.01                   | 0.008                  | 0.009                  | 0.011                  | 0.008                  | 0.006                  | 0.006                  |
| Flexion                        | 0.035                  | 0.047                  | 0.03                   | 0.037                  | 0.037                  | 0.021                  | 0.023                  | 0.043                  |
| Extension                      | 0.041                  | 0.044                  | 0.03                   | 0.041                  | 0.038                  | 0.02                   | 0.02                   | 0.044                  |
| Internal rotation              | 0.077                  | 0.118                  | 0.06                   | 0.077                  | 0.078                  | 0.044                  | 0.043                  | 0.086                  |
| External rotation              | 0.074                  | 0.116                  | 0.05                   | 0.077                  | 0.075                  | 0.046                  | 0.036                  | 0.055                  |

mm: millimeters

Table 3. In the medial oblique fracture model, the distances between the cortices in all loading directions

| Medial oblique fracture model |                        |                        |                        |                        |                        |                        |                        |                        |
|-------------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|
|                               | Fixation method 1 (mm) | Fixation method 2 (mm) | Fixation method 3 (mm) | Fixation method 4 (mm) | Fixation method 5 (mm) | Fixation method 6 (mm) | Fixation method 7 (mm) | Fixation method 8 (mm) |
| Varus                         | 0.008                  | 0.012                  | 0.005                  | 0.013                  | 0.01                   | 0.008                  | 0.007                  | 0.03                   |
| Valgus                        | 0.005                  | 0.008                  | 0.005                  | 0.005                  | 0.006                  | 0.004                  | 0.006                  | 0.007                  |
| Flexion                       | 0.048                  | 0.051                  | 0.023                  | 0.048                  | 0.038                  | 0.018                  | 0.028                  | 0.079                  |
| Extension                     | 0.034                  | 0.052                  | 0.021                  | 0.04                   | 0.032                  | 0.014                  | 0.032                  | 0.089                  |
| Internal rotation             | 0.076                  | 0.132                  | 0.042                  | 0.114                  | 0.093                  | 0.039                  | 0.062                  | 0.202                  |
| External rotation             | 0.094                  | 0.135                  | 0.045                  | 0.125                  | 0.095                  | 0.043                  | 0.074                  | 0.224                  |

mm: millimeters

In the lateral oblique fracture model; FM 7 had the best stability in all loading directions except flexion. FM 6 had the best stability in flexion and had moderate values in all other directions except valgus and external rotation. FM 2 was the weakest fixation method in all directions except valgus (Fig. 5) (Table 2).

In the medial oblique fracture model; FM 6 had the best stability in all directions except the varus. FM 3 was the most stable fixation method against varus and the second stable fixation method in all other directions. FM 8 had the least stability in all loading directions (Fig. 6) (Table 3).

The summary of comparison results is shown in Figure 7.

## DISCUSSION

This study compared the stability of different fixation configurations in high pediatric SHFs using the FEA method. FM 6 (lateral antegrade-lateral retrograde-lateral condylomedullary wires) had the best stability both in torsional and extension loading in TM and all directions except varus in MOM. FM 7 (medial-lateral condylomedullary and lateral antegrade wires) pro-

vided the best stability in all loading directions except flexion in LOM.

In the study where they described SHF patterns, Bahk et al. reported that high fractures occur more proximal in the metaphyseal region than in the broad distal epicondylar region of the typical transverse fractures. They stated that this subtype of SHFs may be problematic because of a less bony healing surface, a smaller area for obtaining adequate purchase with pins, and an increased lever arm for failure. They also stated that more oblique fractures (coronally  $\geq 10^\circ$ , sagittally  $\geq 20^\circ$ ) tend to heal significantly higher in malunion (1). Fayssoux et al. described these fractures as MDJ fractures. They reported that especially transverse fracture patterns in this region had difficulty with reduction and stability achievement. According to them because of the increased surface area for contact between fragments, oblique fracture patterns have more adequate stability in comparison with transverse fractures (5). Sen et al. defined this fracture pattern as supra-supracondylar fracture and they reported that transverse fractures may require surgical treatment with pinning but oblique and comminuted fractures can heal conservatively with a POP cast because of the instability (13). In this study, we created three fracture models. Our models were localized in a high portion of the MDJ area and oblique ones had coronally obliquity of  $30^\circ$ . In this way, we tried to create more unstable fracture types that can be problematic in terms of treatment in clinical practice.

There is no consensus on the fixation method of MDJ fractures in the distal humerus. The main reason for this situation is that the different fracture types need different fixa-

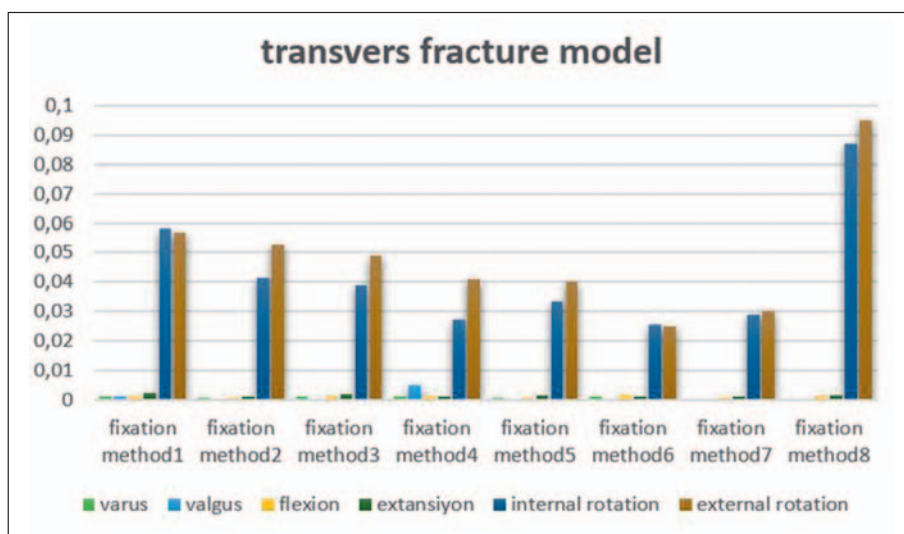


Fig. 4. The comparison of results in the transverse fracture model.

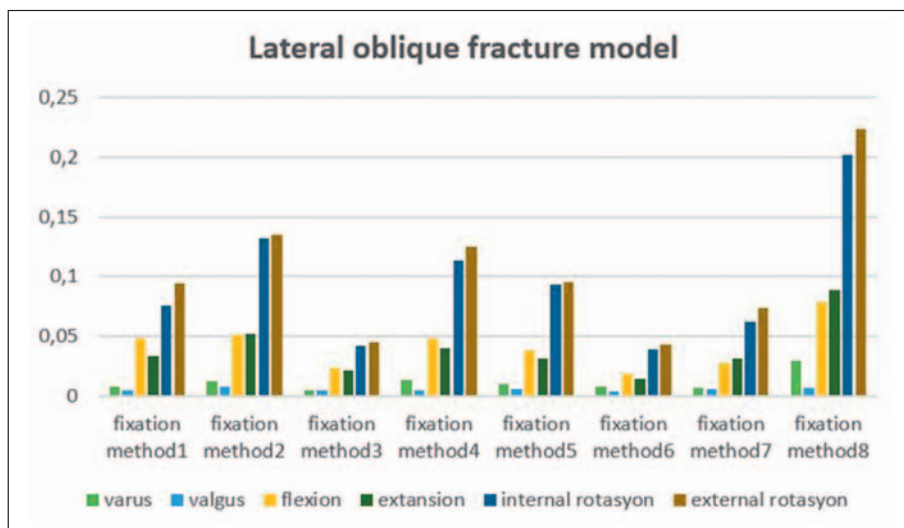


Fig. 5. The comparison of results in the lateral oblique fracture model.

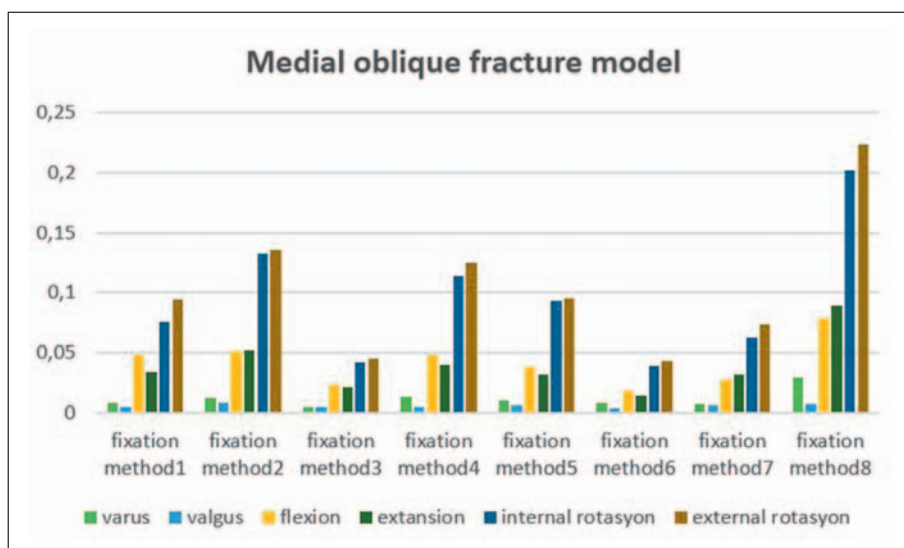


Fig. 6. The comparison of results in the medial oblique fracture model.

tion modalities. In a biomechanic study, Kamara et al. compared the stability of Kirchner wires, EIN, and lateral external fixator. They created sagittally oblique MDJ fractures at three levels (high, medium, low) in fourth-generation composite bone models. They reported that EIN yielded the best stability in all directions while retrograde percutaneous fixation is superior in the lower regions (7). The oblique fracture patterns were not analyzed in this study. Despite the indicated difficulty of percutaneous fixation in high-located fractures, they did not use any different K wire fixation configuration. In the present study, we utilized intramedullary wires (cephalomedullary) and antegrade lateral wires as alternative wire fixation methods. Quellay et al. reported the ten-year results of the antegrade lateral cross-wiring technique (Dorgan's technique) (11). They stated that this method is as good as conventional retrograde cross-wire fixation and lateral entry techniques in terms of fracture stability achievement (11). Fayssoux et al. referred to the difficulty of acquiring cortical purchase because of the high fracture localization. They stated that in some instances, intramedullary pins can be acceptable instead of bicortical wires if the bicortical application is not possible (5). In the present study, FM 6 (1 lateral wire, 1 lateral entry intramedullary wire, and 1 Dorgan wire) had the best stability in all directions except varus in MOM. FM 3 (2 lateral wires and 1 me-

dial wire) had the best stability against varus in MOM. This finding showed that medial entry retrograde wire best resists against the varus moment. Since coronal plane deformities are not expected to remodel spontaneously, preventing varus or valgus malreduction is very important in these fractures because of possible cosmetic deformities. As our study demonstrated, adding K wires both antegrade and intramedullary can increase the stability.

In a previous FEA study, Liu et al. compared the stability of K-wires, elastic stable intramedullary nails, and lateral external fixator in MDJ fractures. They created three fracture models (transverse, 20° sagittally oblique, and 20° coronally oblique) in the mid-portion of the MDJ area and used traditional K-wire fixation methods (two crosses, two lateral and 1 medial retrograde, two divergent laterals, and three divergent laterals). They reported that it was easily possible to place two or three lateral K wires for transverse and lateral oblique fractures (3). We do not agree with this statement for transverse fractures. We experienced difficulties in fixing these fractures with retrograde K wires in many fractures. Especially in high transverse MDJ fractures, it is very difficult to apply two or three divergent K wires. Because of this issue, we used intramedullary (condylomedullary) wires which can be used when one is unable to penetrate the opposite cortex, and also lat-

|                          | varus                                                                                       | valgus                                                                                       | flexion                                                                                  | extension                                                                                  | internal rotation                                                                          | External rotation                                                                         |
|--------------------------|---------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|
| Transvers fracture model | FM1 / +<br>FM2/ +++<br>FM3/ ++<br>FM4/ ++<br>FM5/ ++<br>FM6/ ++<br>FM7/ ++++<br>FM8/ ++++   | FM1 / ++<br>FM2/ +++<br>FM3/ +++<br>FM4/ +<br>FM5/ ++++<br>FM6/ +++<br>FM7/ +++<br>FM8/ ++++ | FM1 / ++<br>FM2/ ++++<br>FM3/ ++<br>FM4/ ++<br>FM5/ ++++<br>FM6/ +<br>FM7/ ++<br>FM8/ ++ | FM1 / +<br>FM2/ ++++<br>FM3/ ++<br>FM4/ +++<br>FM5/ ++<br>FM6/ ++++<br>FM7/ +++<br>FM8/ ++ | FM1 / ++<br>FM2/ ++<br>FM3/ ++<br>FM4/ +++<br>FM5/ ++<br>FM6/ ++++<br>FM7/ +++<br>FM8/ +   | FM1 / ++<br>FM2/ ++<br>FM3/ ++<br>FM4/ ++<br>FM5/ ++<br>FM6/ ++++<br>FM7/ +++<br>FM8/ +   |
| Lateral oblique model    | FM1 / ++++<br>FM2/ +<br>FM3/ +++<br>FM4/ +++<br>FM5/ ++<br>FM6/ ++++<br>FM7/ ++++<br>FM8/ + | FM1 / +<br>FM2/ ++<br>FM3/ +++<br>FM4/ ++<br>FM5/ +<br>FM6/ +++<br>FM7/ ++++<br>FM8/ ++++    | FM1 / ++<br>FM2/ +<br>FM3/ +++<br>FM4/ ++<br>FM5/ ++<br>FM6/ ++++<br>FM7/ ++++<br>FM8/ + | FM1 / ++<br>FM2/ +<br>FM3/ +++<br>FM4/ ++<br>FM5/ ++<br>FM6/ ++++<br>FM7/ ++++<br>FM8/ +   | FM1 / ++<br>FM2/ +<br>FM3/ +++<br>FM4/ ++<br>FM5/ ++<br>FM6/ ++++<br>FM7/ ++++<br>FM8/ ++  | FM1 / ++<br>FM2/ +<br>FM3/ +++<br>FM4/ ++<br>FM5/ ++<br>FM6/ +++<br>FM7/ ++++<br>FM8/ +++ |
| Medial oblique model     | FM1 / ++<br>FM2/ ++<br>FM3/ ++++<br>FM4/ ++<br>FM5/ ++<br>FM6/ +++<br>FM7/ +++<br>FM8/ +    | FM1 / +++<br>FM2/ +<br>FM3/ +++<br>FM4/ +++<br>FM5/ ++<br>FM6/ ++++<br>FM7/ ++<br>FM8/ ++    | FM1 / ++<br>FM2/ ++<br>FM3/ +++<br>FM4/ ++<br>FM5/ ++<br>FM6/ ++++<br>FM7/ +++<br>FM8/ + | FM1 / ++<br>FM2/ ++<br>FM3/ +++<br>FM4/ ++<br>FM5/ ++<br>FM6/ ++++<br>FM7/ ++<br>FM8/ +    | FM1 / +++<br>FM2/ ++<br>FM3/ ++++<br>FM4/ ++<br>FM5/ ++<br>FM6/ ++++<br>FM7/ +++<br>FM8/ + | FM1 / ++<br>FM2/ ++<br>FM3/ ++++<br>FM4/ ++<br>FM5/ ++<br>FM6/ ++++<br>FM7/ +++<br>FM8/ + |

++++: high stable fixation, +++: moderate stable fixation, ++: mild stable fixation, +: low stable fixation  
FM: fixation method

Fig. 7. The summary of comparison results of fracture models in all loading directions.

eral antegrade wires. The oblique fractures can be fixed either medially or laterally according to the fracture configuration, but it is very difficult in transverse fractures.

According to their fixations models of a biomechanical study, Kamara et al. showed that elastic stable intramedullary nails had the best overall stabilizing capability in the high fracture of MDJ (7) and these findings were supported by some other clinical studies (2, 6, 10). Liu et al. showed that elastic stable intramedullary nails performed poorly in their transverse and medial oblique fracture models. Especially that was weakest against translational forces in the medial oblique model and remained weaker against torsional forces in the lateral oblique model (9). Zhou et al. maintained axial stability by condylomedullary K-wire first and then they applied a medial-lateral cross pin. They suggested that the intramedullary K-wire insertion gives a great degree of stability to the MDJ fractures (15). We used pure intramedullary fixation in two methods (FM 2 and FM 5). FM 5 was stronger than FM 2 in all fracture types but both of them were weaker, especially against the torsional forces. Condylomedullary fixation showed good stability against flexion and extension forces only in the transverse fracture model. At the fracture site, the distance of nails or wires can not be far enough to obtain stability in these high fractures, this issue can be the reason for such instability.

In this current study, FM 8 (one proximal lateral to distal medial wire and one lateral entry intramedullary wire) had the least stability in all fracture models against all loading directions except valgus in the lateral oblique fracture model. The stability of this fixation model had significantly increased by adding a lateral entry wire (FM 6) or medial condylomedullary wire (FM 7). Because of these findings, we thought that these types of wires do not have to be used alone instead, they can be a part of the final fixation construct. Lower stability can be achieved with cross pinning with single wire (FM 1) because both the place where the wires cross each other and the exit points of the wires in the cortices are close to the fracture line.

There were some limitations of this study. Firstly, we applied the deforming forces in all directions separately but in real life, these forces act on fractures in combination. We did not change our fixation method according to the fracture type and also we could not evaluate soft tissue effects such as periosteal continuity or disruption for secondary displacements. When these factors are considered together our results may not seem to mimic the real scenarios. But we believe that our findings can provide important information, especially about the possible direction of reduction loss. In this way, orthopedic surgeons can consider these methods in the preoperative planning of different fracture types. Secondly, the values in actual conditions and those obtained in this study may be different because finite element analysis can not provide real conditions. Nevertheless, because the constructed model was the

same for all fracture and fixation types, the obtained results were sufficient for comparing the fixation methods in each fracture model.

In conclusion, different types of MDJ SHFs may need different fixation modalities. Traditional fixation techniques may not work all the time. The application of condylomedullary K-wires and antegrade lateral to medial K wires can be used as a part of the final fixation construct. While the lateral condylomedullary-lateral antegrade wire method (FM 8) was a weak fixation method in TM and MOM, the lateral retrograde-lateral antegrade-lateral condylomedullary wire method (FM 6) in LOM and the medial-lateral condylomedullary-lateral antegrade wire method (FM 7) in MOM showed acceptable stability.

In SHFs, some rotational deformities can be tolerated by wide shoulder motion. The deformities such as flexion and extension in the sagittal plane may not cause any functional limitation and may eventually remodel during growth (4). However, coronal plane deformities like varus and valgus are not acceptable because of functional and cosmetic problems. According to the results of this study, medial-lateral condylomedullary and lateral antegrade wires provided the best stability against varus in transverse and lateral oblique fracture models. Cross pinning with two lateral and single medial wires had the best stability against varus in the medial oblique fracture model.

## CONCLUSIONS

Combining lateral antegrade with lateral retrograde wire and lateral condylomedullary wire provides strong stability in the lateral oblique fracture. Two condylomedullary Kirchner wires and one antegrade lateral wire results in a strong stability in the medial oblique fracture. Medial-lateral condylomedullary and lateral antegrade wires provided the best stability against varus in transverse and lateral oblique fractures.

## References

1. Bahk MS, Srikumaran U, Ain MC, Erkula G, Leet AI, Sargent MC, Sponseller PD. Patterns of pediatric supracondylar humerus fractures. *J Pediatr Orthop.* 2008;28:493–499.
2. De Gheldere A. Re: Article by Fayssoux et al. entitled “Fractures of the distal humeral metaphyseal-diaphyseal junction in children”. (*J Pediatr Orthop.* 2008;28:142–146), *J Pediatr Orthop.* 2010;30:746–747.
3. Durusoy S, Öner K, Özer A, Sevinç HF. The effect of the angle between fracture line and Kirschner wires on stability in supracondylar humerus fractures treated with Kirschner wire fixation: A finite element analysis. *Jt Dis Relat Surg.* 2021;32:75–84.
4. Ecklund K, Jaramillo D. Patterns of premature physal arrest: MR imaging of 111 children. *AJR Am J Roentgenol.* 2002;178:967–972.
5. Fayssoux RS, Stankovits L, Domzalski ME, Guille JT. Fractures of the distal humeral metaphyseal-diaphyseal junction in children. *J Pediatr Orthop.* 2008;28:142–146.
6. Ge YH, Wang ZG, Cai HQ, Yang J, Xu YL, Li YC. Flexible intramedullary nailing had better outcomes than Kirschner wire

- fixation in children with distal humeral metaphyseal-diaphyseal junction fracture: a retrospective observational analysis. *Int J Clin Exp Med*. 2014;7:3568–3572.
7. Kamara A, Ji X, Liu T, Zhan Y, Li J, Wang E. A comparative biomechanical study on different fixation techniques in the management of transverse metaphyseal-diaphyseal junction fractures of the distal humerus in children. *Int Orthop*. 2019;43:411–416.
  8. Ling M, Zhan S, Jiang D, Hu H, Zhang C. Where should Kirschner wires be placed when fixing patella fracture with modified tension-band wiring? A finite element analysis. *J Orthop Surg Res*. 2019;14:14.
  9. Liu C, Kamara A, Liu T, Yan Y, Wang E. Mechanical stability study of three techniques used in the fixation of transverse and oblique metaphyseal-diaphyseal junction fractures of the distal humerus in children: a finite element analysis. *J Orthop Surg Res*. 2020;15:34.
  10. Marengo L, Canavese F, Cravino M, De Rosa V, Rousset M, Samba A, Mansour M, Andreacchio A. Outcome of displaced fractures of the distal metaphyseal-diaphyseal junction of the humerus in children treated with elastic stable intramedullary nails. *J Pediatr Orthop*. 2015;35:611–616.
  11. Queally JM, Paramanathan N, Walsh JC, Moran CJ, Shannon FJ, D'Souza LG. Dorgan's lateral cross-wiring of supracondylar fractures of the humerus in children: A retrospective review. *Injury*. 2010;41:568–571.
  12. Reisoglu A, Kazimoglu C, Hanay E, Agus H. Is pin configuration the only factor causing loss of reduction in the management of pediatric type III supracondylar fractures? *Acta Orthop Traumatol Turc*. 2017;51:34–38.
  13. Sen RK, Tripathy SK, Kumar A, Agarwal A, Aggarwal S, Dhatt S. Metaphyseal-diaphyseal junction fracture of the distal humerus in children. *J Pediatr Orthop B*. 2012;21:109–114.
  14. Shah M, Han JH, Park H, Kim HW, Park KB. Prevalence and treatment outcome of displaced high-long oblique supracondylar humeral fractures in children. *Front Pediatr*. 2021;9:739909.
  15. Zhou H, Zhang G, Li M, Liu X, Qu X, Cao Y, Weng L, Zhang Y. Closed reduction and percutaneous pinning in the treatment of humeral distal metaphyseal-diaphyseal junction fractures in children: a technique note and preliminary results. *Front Pediatr*. 2021;9:670164.

**Corresponding author:**

Muhammet Bozoğlan, MD.

University of Health Sciences, İzmir

Tepecik Health Research Center

Orthopedics and Traumatology Department

İzmir, Turkey

E-mail: mbozoglan@gmail.com