ACTA ORTHOPAEDICA et TRAUMATOLOGICA TURCICA
www.aott.org.tr

Research Article

A new configuration of lateral-pin fixation for pediatric supracondylar humeral fracture: A biomechanical analysis

Fuat Bilgili[1], Mehmet Demirel[1], Fevzi Birişik[2], Halil İbrahim Balcı[1], Emin Sunbuloglu[3], Ergun Bozdag[3]

[1]*Department of Orthopaedics and Traumatology, İstanbul University, İstanbul School of Medicine, İstanbul, Turkey*
[2]*Department of Orthopaedics and Traumatology, Istanbul Training and Research Hospital, University of Health Sciences, Istanbul, Turkey*
[3]*Department of Mechanical Engineering, Istanbul Technical University, Istanbul, Turkey*

ARTICLE INFO

Article history:
Submitted February 24, 2021
Received in revised form January 29, 2022
Last revision received form October 24, 2022
Accepted September 28, 2023
Publication Date March 1, 2024

Keywords:
Biomechanical analysis
Crossed pins
Lateral divergent pins
Pediatric supracondylar humerus fracture
Torsional stability

ORCID iDs of the authors:
F.B. 0000-0003-2449-8264;
M.D. 0000-0003-1131-7719;
F.B. 0000-0001-7450-8825;
H.İ.B. 0000-0001-7472-2901;
E.S. 0000-0001-9930-4618;
E.B. 0000-0002-8942-6627.

ABSTRACT

Objective: The aim of this study was to biomechanically compare a new lateral-pinning technique, in which pins engage the medial and lateral columns of the distal humerus in a divergent configuration in both the axial and sagittal planes instead of the coronal plane, with the cross-pin, and with 2 and 3 coronally divergent lateral-pin techniques in a synthetic humerus model of supracondylar humerus fractures.

Methods: Thirty-six identical synthetic models of the humerus simulating a standardized supracondylar humerus fracture were included in this study. They were divided into 4 groups based on the pin configuration of fixation: the new 3-lateral pin-fixation technique (group A), 2 crossed pins (group B), 3 divergent lateral pins (group C), and 2 divergent lateral pins (group D). Each model was subjected to combined axial and torsional loading, and then torsional stability and torsional stiffness (N mm/°) were recorded.

Results: Group A had greater rotational stability than groups C and D but had no statistically significant additional rotational stability compared with group B (P=.042, P=.008, P=.648, respectively), whereas group B had greater rotational stability than only group D (P=.020). Furthermore, group A demonstrated higher internal rotational stiffness compared with groups C and D (P=.038, P=.006, respectively). Group B had better internal rotational stiffness than group D (P=.015). There was no significant difference in internal rotational stiffness between groups A and B (P=. 542), groups B and C (P=.804), and groups D and C (P=.352). Although no statistically significant differences existed between groups A and B, the modified pin configuration exhibited the highest torsional stability and stiffness. Group D showed the lowest values in all biomechanical properties.

Conclusion: This study has shown us that this new lateral-pinning technique may provide torsional resistance to internal rotational displacement as strong as the standard technique of crossed-pin configuration of fixation. Furthermore, with this new pin configuration, greater torsional resistance can be obtained than with either the standard 2- or the standard 3-lateral divergent pin configuration.

Introduction

The literature remains controversial regarding the optimal pin configuration in the treatment of supracondylar humeral fractures in children.[1,2] A crossed-pin configuration has been traditionally cited as the most stable construct, especially in torsional loading, but medial pinning is related to a potential risk of iatrogenic injury to the ulnar nerve.[3-5] Conversely, although the advantage of lateral-entry pins alone in the divergent or parallel configuration is to prevent the iatrogenic ulnar nerve injury, constructs may offer lower torsional resistance to rotational displacement.[6]

According to our review of the literature, in order to optimize stability and avoid iatrogenic ulnar nerve injury, lateral-entry pin configurations described to date have been designed predominantly based on the frontal plane.[3-11] Nonetheless, optimal initial stability would depend on the pin placement not only in the frontal plane but also in the sagittal and axial planes. Therefore, considering the unique triangular-shaped anatomy of the distal humerus comprised by the medial and lateral columns and deforming torsional stresses to this region,[12] we have designed a new configuration of 3 divergent lateral-entry pins in order to improve torsional stability, which connects the lateral column to the anterior, posterior, and medial cortices of the medial column in a divergent configuration in both the axial and sagittal planes instead of the coronal plane.

This study aimed to biomechanically test and compare the torsional stability and torsional stiffness of our new lateral-pinning technique with the cross-pin (medial and lateral entry) and 2 divergent lateral-pin techniques in a synthetic humerus model of supracondylar humerus fractures. We hypothesized that our new technique would provide greater resistance to internal rotational displacement than the other standard pin configurations.

Materials and methods

Biomechanical features of different pin configurations under combined axial and torsional loading were compared on a synthetic model of supracondylar

Corresponding author:
Fuat Bilgili
fuatbilgili@gmail.com

Content of this journal is licensed under a Creative Commons Attribution-NonCommercial 4.0 International License.

Cite this article as: *Bilgili F, Demirel M, Birişik F, Balcı Hİ, Sunbuloglu E, Bozdag E. A new configuration of lateral-pin fixation for pediatric supracondylar humeral fracture: A biomechanical analysis. Acta Orthop Traumatol Turc., 2024;58(2):110-115.*

DOI: 10.5152/j.aott.2024.21091

humerus fractures. Ethical approval is not required for a sawbone or artifical bone studies.

A total of 36 identical synthetic models of the left humerus were used in the study. The models (Sawbones Model#1028®, Pacific Research Laboratories, Vashon Island, Wash, USA) were manufactured from specifically formulated rigid foam, including an inner cancellous material and a harder outer shell that closely simulate the mechanical and anatomical features of the human bone.

In simulating a standardized supracondylar humerus fracture pattern, a transverse osteotomy perpendicular to the anatomic axis of the humerus, crossing the tip of the olecranon fossa at the level of the epicondyles, was uniformly created using a circular saw and cutting guide in each model. The models were then divided into 4 groups (9 models for each), and osteotomy sites were anatomically reduced and stabilized by 0.062" K-wires using a custom-made positioning device specified for each pin configuration (Figure 1) in 1 of the following 3 configurations:

- Group A. The new technique of lateral-pin fixation: 3 lateral K-wires were inserted, one of which was placed through the lateral epicondyle-entry point to stabilize the medial cortex, and the other 2 were placed from the capitellar entry point to the anteromedial and posteromedial cortex of the distal diaphysis, respectively (Figure 2). Furthermore, the 2 pins with more lateral placement were inserted in a divergent configuration, and the third pin with more medial placement was inserted in a convergent configuration to the others (Figure 3).

HIGHLIGHTS

- The optimal pin configuration in the treatment of supracondylar humeral fractures in children remains controversial.
- A crossed-pin configuration has been traditionally cited as the most stable construct, but it is also related to a potential risk of iatrogenic injury to the ulnar nerve.
- Lateral-entry pins alone, whether in a divergent or parallel configuration, eliminate the risk of iatrogenic ulnar nerve injury but may offer lower torsional resistance to rotational displacement.
- Our pin-fixation technique, reflecting divergent placement of 3 pins in the axial and sagittal planes, can provide torsional resistance as strong as the standard crossed-pin configuration.

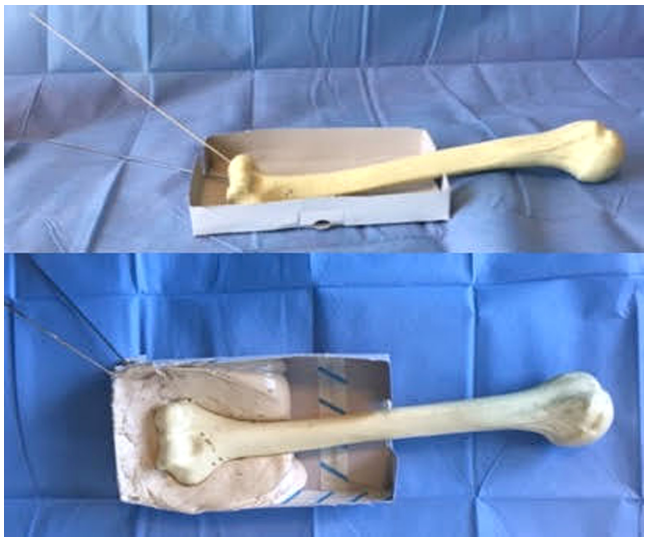

Figure 1. A custom-made positioning device specified for each pin configuration to provide standardization of pin placement.

- Group B. Two crossed pins, a medial and a lateral K-wire, were placed from the medial and lateral condyles, as described by Swenson et al[13] (Figure 4).
- Group C. Three divergent lateral pins: As described by Skaggs et al,[14] 3 pins were placed, maximally separating at the fracture site and engaging the lateral and medial columns (Figure 5).
- Group D. Two divergent lateral pins: As described by Hamdi et al,[15] a lateral pin was placed parallel to the lateral metaphyseal flare of the humerus, and the second pin crossed the osteotomy site at the medial edge of the coronoid fossa (Figure 6).

After forming the models of supracondylar humerus fracture, each sample was cut from the middle part of the diaphysis in order to minimize possible tensile bending stresses secondary to axial loading. Subsequently, all models were fixed in a PVC pipe (diameter: 50 mm; depth: 50 mm) using polyester paste (Politek® İstanbul/Türkiye) and mounted in a stable position in a particularly constructed apparatus, holding the humerus in a vertical position and providing the supracondylar region to be stabilized in a neutral position (Figure 7).

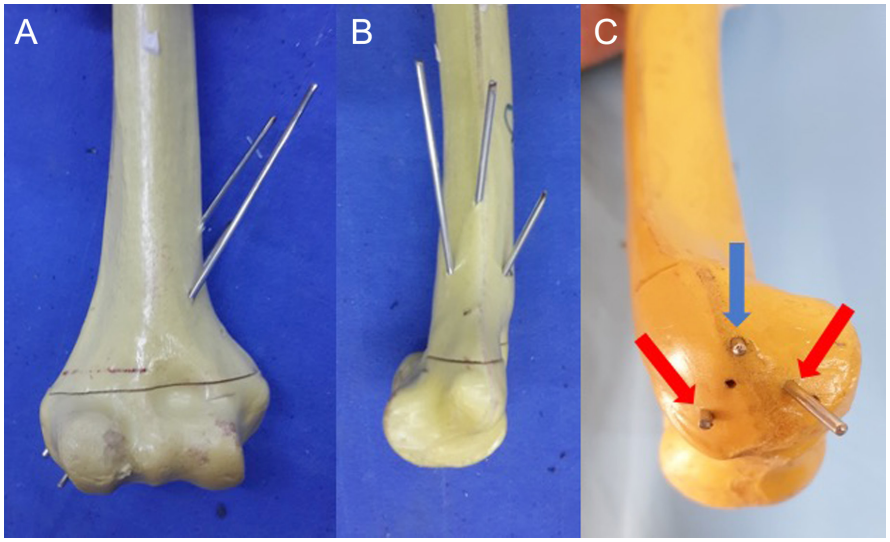

Figure 2. Anteroposterior (A), mediolateral (B), and posterolateral views of the sample showing our new technique of the 3-lateral entry-pin configuration in the coronal (A), sagittal (B), and axial (C) planes. Note that capitellar (red arrows) and lateral epicondyle-entry points (blue arrow) (C).

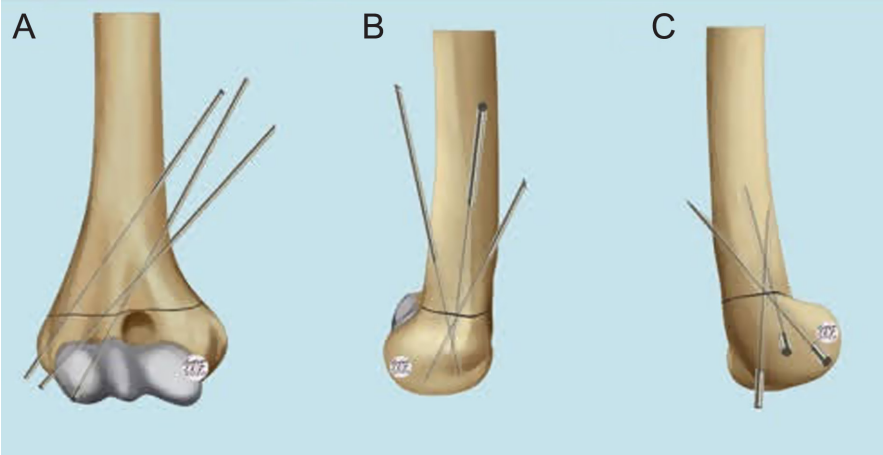

Figure 3. Representative figures illustrating our technique, which connects the lateral column to anterior, posterior, and medial cortices of the medial column in a divergent configuration in both the axial and sagittal planes (B and C) instead of the coronal plane (A).

Biomechanical testing

In our case, axial loading and torsion moment were applied at the same time, using a servohydraulic materials testing machine (MTS 858 Mini Bionix II, Eden, Prairie, Minn, USA). While 100 N constant force was applied to each sample, at the same time, the humerus models were rotated about the section that has undergone the operation with a speed of 0.5 degrees per second. Torque was applied until damage occurred in the specimens. During the test, force, rotational speed, and torsion data were recorded in real time. Obtained test data were used to plot torsional moment (Nm) and rotational angle (°) values. Then, the stiffness value (N mm/°) of each sample was determined with the help of these graphs.

Statistical analyses

All statistical analyses were conducted using Statistical Package for Social Science Statistics software, version 20.0 (IBM SPSS Corp.; Armonk, NY, USA). A *P*-value < .05 was considered significant. Statistical differences among groups were analyzed after confirmation of a normal distribution (Kolmogorov–Smirnov test). For normally distributed samples, we used a 1-way analysis of variance test for comparisons of more than 2 groups followed by an unpaired 2-tailed *t*-test with Welch correction for 2-group comparisons.

Figure 5. Anteroposterior view of the sample illustrating the standard 3 divergent lateral-entry pin configuration.

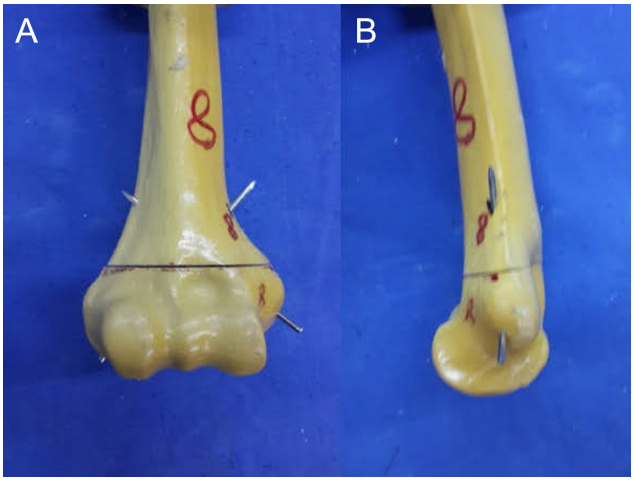

Figure 4. Anteroposterior (A) and mediolateral views (B) of the sample demonstrating standard 2 crossed-pin configuration.

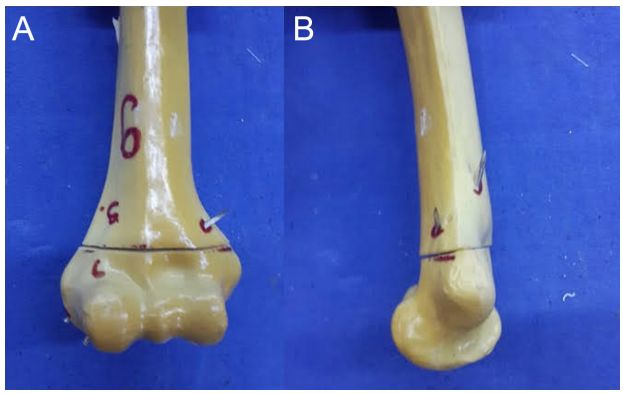

Figure 6. Anteroposterior (A) and mediolateral views (B) of the sample illustrating the standard 2 divergent lateral-entry pin configuration.

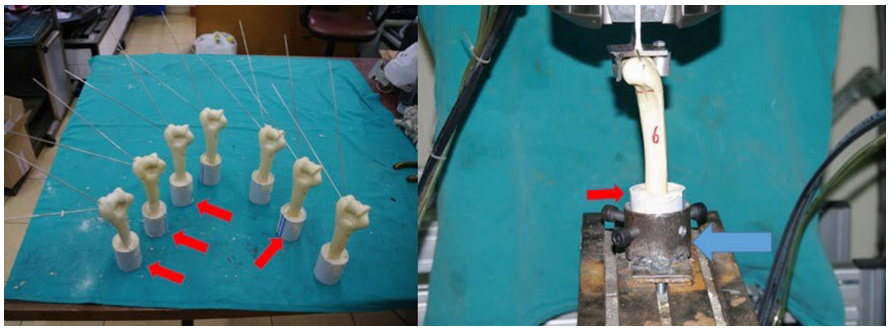

Figure 7. Fixing the sample in a PVC pipe using polyester paste before combined axial and torsional loading tests (red arrows) and placing the sample in a specifically constructed apparatus (blue arrow).

Results

Assessment of torsional stability

With regard to torsional stability, significant differences were determined among groups ($P < .001$). Post-hoc tests ($P < .05$) indicated significant differences between groups A and C ($P = .042$); groups A and D ($P = .008$); and groups B and D ($P = .020$), but there was no significant difference between groups A and B ($P = .648$); groups B and C ($P = .907$); and groups D and C ($P = .378$).

Assessment of torsional stiffness

The torsional stiffness data are given in Table 1-2 and Figure 8-9 Torsional stiffness refers to the torque required to generate an identical angle of twist and calculated as the ratio between applied torque and the angle of deformation. Thus, torsional stiffness during internal rotation was calculated using plots of torsional torque against torsional angle (Table 1-2 and Figure 8-9).

Similar to torsional stability, significant differences were determined among groups ($P < .001$). Post-hoc tests ($P < .05$) revealed significant differences between groups A and C ($P = .038$), groups A and D ($P = .006$), and groups B and D ($P = .015$), but there was no significant difference between groups A and B ($P = .542$), groups B and C ($P = .804$), and groups D and C ($P = .352$).

Table 1. Torsional torque data required to generate various degrees of internal rotation for different pin configurations

	Torque (Nm)		
Pin configuration	**5° of rotation**	**10° of rotation**	**15° of rotation**
Group A			
Minimum-maximum	1.6-2.2	2.9-3.7	3.7-4.8
Mean ± SD	2.4 ± 1.1	3.2 ± 2	3.9 ± 2
Group B			
Minimum-maximum	1.4-1.8	2.5-3.5	2.9-4.5
Mean ± SD	1.6 ± 1.8	3 ± 2.3	3.4 ± 2.2
Group C			
Minimum-maximum	1.3-1.6	2.3-3.2	2.6-3.7
Mean ± SD	1.5 ± 1.2	2.6 ± 1.8	3.2 ± 2.2
Group D			
Minimum-maximum	0.9-1.5	1.7-3	2.3-3.6
Mean ± SD	1.2 ± 2.4	2.5 ± 2.6	3.1 ± 2.1

Table 2. Torsional stiffness data of different pin configurations

	Stiffness (N mm/degree)		
Pin configuration	**Mean ± SD**	**Minimum**	**Maximum**
Group A	352 ± 47.01	302	443
Group B	328 ± 18.16	296	357
Group C	308 ± 44.96	245	355
Group D	261 ± 43.22	199	309

Discussion

The main biomechanical disadvantage of 2 divergent lateral-entry pins has been reported to offer lower torsional resistance, especially to internal rotation that may cause a cubitus varus deformity, than do 2 crossed pins.[3,16] To overcome this disadvantage, we intended to develop a novel 3-lateral entry-pin construct that can provide greater torsional resistance, thus eliminating the need for medial pinning and its potential complication, iatrogenic injury to the ulnar nerve.

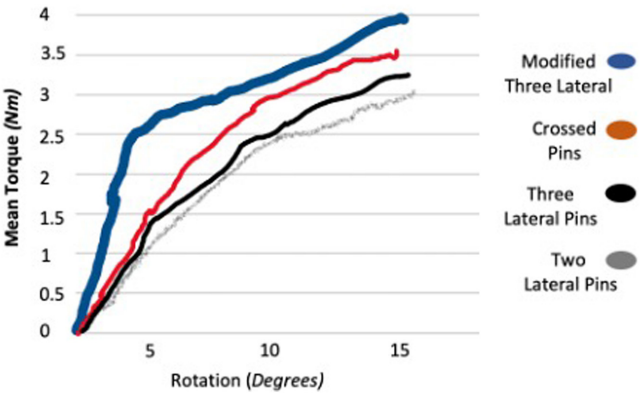

Figure 8. Plot of torsional torque vs. torsional angle (rotational displacement). Note that the slope of the curves of each pin configuration illustrates a decreasing trend following 5° of internal rotation, which indicates that less additional force is needed to generate further increases of rotational displacement. Also note that the torque required to generate a certain amount of rotation is highest with the modified 3lateral divergent pins at all degrees.

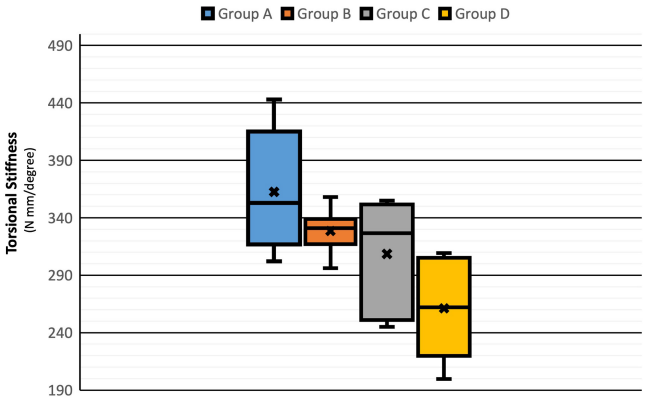

Figure 9. Box and Whisker diagram showing distribution of torsional stiffness values (N mm/°) of different pin configurations. Group A vs. C: $P = .038$; group A vs. D: $P = .006$; group B vs. D: $P = .015$ ($P < .05$); group A vs. B: $P = .542$; group B vs. C: $P = .804$; group D vs. C: $P = .352$ ($P > .05$).

The biomechanical results of the current study have shown no statistically significant differences between our new pin configuration and standard crossed pins in terms of torsional stability and stiffness. However, the pattern of findings has pointed out that the new pin configuration is the most stable construct with the highest torsional stiffness. Accordingly, these findings partially support our hypothesis that our new technique of 3-lateral pin fixation would provide greater resistance to internal rotational displacement than the other pin configurations.

Skaggs et al[14] described significant technical pitfalls of fixation with 2 divergent lateral-entry pins, particularly maximizing pin separation at the fracture site and engaging adequate bone in both distal and proximal fragments. The authors also suggested that if the surgeon has any concern about the fracture stability or whether the pin placement is optimal, a third pin should be inserted from the lateral side as well. Furthermore, more recent clinical[8,17,18] and biomechanical studies[11,19,20] have supported the use of lateral pin constructs for the treatment of supracondylar humerus fractures with favorable outcomes. We designed to place 3 lateral-entry pins in a divergent configuration similar to Skaggs et al' suggestions,[14] but with an important difference. Contrary to the classic pattern of 3 divergent lateral-entry pins, we primarily aimed to maximize pin separation at the other 2 planes (axial and sagittal) instead of the coronal plane, thus improving rotational stability more. To achieve this aim, 2 pins with more lateral placement were inserted in a divergent configuration, and the third pin with more medial placement was inserted in a convergent configuration to the others. Our new pin configuration exhibited statistically higher torsional stability and stiffness than 3-lateral standard divergent pins. Thus, the current study has shown that maximizing pin separation at both the axial and sagittal planes can improve rotational stability more.

It also should be emphasized that the effect of starting points of pins is of great importance concerning fracture stability. Biomechanical studies presented illustrations depicting that all pins stay extraarticular with a direct lateral starting point.[15,21] In contrast, other publications[7,14,22] have illustrated more capitellar or paraolecranon starting points for the pins with most distal placement. More recently, Gottschalk et al[9] have biomechanically compared the stiffness of different pin configurations for pin entry and number of pins and observed an increased stiffness in terms of internal rotation with the capitellar starting point. The results of the current study are in agreement with Gottschalk et al, who suggested that the capitellar starting point presents several advantages, including the ability to engage the bone of the distal fragment and maximize pin separations across the fracture area.

The main strength of this study lies in the fact that it is the first biomechanical study dealing with a 3-dimensional pin configuration in the percutaneous pinning of supracondylar humerus fractures in children. Many previous studies have analyzed the ideal number, size, starting point, and configuration of the pin placement.[3-7,9,11,19] Nevertheless, to the best of our knowledge, pin configurations analyzed in these studies[3-7,9,11,19] have been designed by almost entirely considering the frontal plane, thus neglecting the other 2 planes (axial and sagittal). However, the distal part of the humerus has a unique triangular-shaped anatomy composed of medial and lateral columns. Therefore, unlike most studies on the topic, corresponding to this triangular-shaped anatomy of the medial column including 3 aspects, a novel 3-lateral pin configuration has been developed in the present study, which engages the medial and lateral columns in a divergent configuration in both the axial and sagittal planes instead of the coronal plane.

The second issue regarding the pin configuration is iatrogenic nerve injury to the ulnar nerve with the use of the medial pin.[23] The cross-pinning technique is reported to carry a higher risk for iatrogenic injury to the ulnar nerve than the lateral-pinning technique.[24,25] Some biomechanical studies[7,21] have reported that the standard crossed pins or the addition of a medial crossed pin to 2 divergent lateral pins improve the rotational stability compared with lateral-entry pins alone. We consider that our new technique may eliminate the need for medial pinning and its potential complications while offering satisfactory torsional stability and stiffness to prevent the cubitus varus deformity.

Limitations of the study

The main limitation of this study involves the use of synthetic humerus models to evaluate biomechanical properties. However, synthetic humerus models are easily accessible, relatively economical, and offer limited interspecimen variability, compared with adult cadaveric specimens that have been utilized in a previous biomechanical study of pin-fixation techniques.[3] Additionally, our study design and the number of samples used are consistent with many previous studies cited above in which synthetic humerus models were used to evaluate the biomechanical features of percutaneous pinning. The certain values for the torsional stability and stiffness of a synthetic model, of course, will be distinct from those of a pediatric humerus in vivo, but a synthetic humerus does confer an anatomically correct means to ascertain the relative rotational stability and stiffness presented by the different pin configurations. Another limitation was to assess only internal rotational displacement. However, cubitus varus deformity, in combination with internal rotation and hyperextension malalignment, represents the most commonly observed residual deformity after treatment of supracondylar humerus fractures.[3] Internal rotation of the distal humerus has been attributed as the main cause of this deformity.[3,26] Furthermore, in clinical practice, the arm is generally put in plaster after the operation, and the internal rotation is the major deforming force in this position. Accordingly, we specifically chose to compare the torsional resistance of different pin configurations to internal rotational displacement.

The clinical relevance of our new pin-fixation technique is another important topic. The findings of the present study have shown that divergent placement of lateral 3 pins in the axial and sagittal planes instead of the coronal plane can offer favorable biomechanical performance. However, the biomechanical findings were obtained from sawbones without soft tissue attachments, and thus future clinical studies are needed to confirm the clinical utility of our lateral fixation technique.

In conclusion, our new pin-fixation technique, reflecting the divergent placement of 3 pins in the axial and sagittal planes instead of the coronal plane, can provide torsional resistance as strong as the standard crossed-pin configuration without applying a pin from the medial side of the elbow. Also, with this new pin configuration, greater torsional resistance can be obtained than both the standard 2-pin and the standard 3-lateral divergent pin configuration.

Ethics committee approval: Ethical approval is not required for a sawbone or artifical bone studies.

Informed consent: N/A

Peer-review: Externally peer-reviewed.

Author contributions: Concept – F.B., M.D., H.İ.B.; Design –F.B., M.D., H.İ.B.; Supervision – F.B., H.İ.B.; Resources – F.E., B.; Materials – M.D., F.E.B., E.S.; Data Collection and/or Processing – E.B., E.S., M.D.; Analysis and/or Interpretation – E.B., M.D., H.İ.B., F.B.; Literature Search – M.D., F.B.; Writing – M.D.; Critical Review – F.B., H.İ.B., F.E.B., E.B.

Declaration of interests: The authors have no conflict of interest to declare.

Funding: The authors declared that this study has received no financial support.

References

1. Omid R, Choi PD, Skaggs DL. Supracondylar humeral fractures in children. *J Bone Joint Surg Am*. 2008;90(5):1121-1132. [CrossRef]
2. Zorrilla S de Neira JZS, Prada-Cañizares A, Marti-Ciruelos R, Pretell-Mazzini J. Supracondylar humeral fractures in children: current concepts for management and prognosis. *Int Orthop*. 2015;39(11):2287-2296. [CrossRef]
3. Zionts LE, McKellop HA, Hathaway R. Torsional strength of pin configurations used to fix supracondylar fractures of the humerus in children. *J Bone Joint Surg Am Volume*. 1994;76(2):253-256. [CrossRef]
4. Herzenberg J, Koreska J, Carroll N, Rang M. Biomechanical testing of pin fixation techniques for pediatric supracondylar elbow fractures. *Orthopade Trans*. 1988;12:678-679.
5. Pirone AM, Graham HK, Krajbich JI. Management of displaced extension-type supracondylar fractures of the humerus in children. *J Bone Joint Surg Am Volume*. 1988;70(5):641-650. [CrossRef]
6. Lee SS, Mahar AT, Miesen D, Newton PO. Displaced pediatric supracondylar humerus fractures: biomechanical analysis of percutaneous pinning techniques. *J Pediatr Orthop*. 2002;22(4):440-443. [CrossRef]
7. Larson L, Firoozbakhsh K, Passarelli R, Bosch P. Biomechanical analysis of pinning techniques for pediatric supracondylar humerus fractures. *J Pediatr Orthop*. 2006;26(5):573-578. [CrossRef]
8. Segal D, Cobb L, Little KJ. Fracture obliquity is a predictor for loss of reduction in supracondylar humeral fractures in older children. *J Pediatr Orthop B*. 2020;29(2):105-116. [CrossRef]
9. Gottschalk HP, Sagoo D, Glaser D, Doan J, Edmonds EW, Schlechter J. Biomechanical analysis of pin placement for pediatric supracondylar humerus fractures: does starting point, pin size, and number matter? *J Pediatr Orthop*. 2012;32(5):445-451. [CrossRef]
10. Tamrakar R, Khanal R, Acharya BM, Pradhan NMS, Shrestha SK. Three lateral divergent pinning for displaced supracondylar humerus fractures in children. *J Patan Acad Health Sci*. 2014;1(2):30-34. [CrossRef]
11. Wallace M, Johnson DB, Pierce W, Iobst C, Riccio A, Wimberly RL. Biomechanical assessment of torsional stiffness in a supracondylar humerus fracture model. *J Pediatr Orthop*. 2019;39(3):e210-e215. [CrossRef]
12. Bruce WD, Brown HP. Supracondylar fractures of the humerus in children. *Operative Treatment of Elbow Injuries*. Springer; Berlin; 2002:223-243.
13. Swenson AL. The treatment of supracondylar fractures of the humerus by Kirschner-wire transfixion. *JBJS*. 1948;30(4):993-997.
14. Skaggs DL, Cluck MW, Mostofi A, Flynn JM, Kay RM. Lateral-entry pin fixation in the management of supracondylar fractures in children. *J Bone Joint Surg Am*. 2004;86(4):702-707. [CrossRef]
15. Hamdi A, Poitras P, Louati H, Dagenais S, Masquijo JJ, Kontio K. Biomechanical analysis of lateral pin placements for pediatric supracondylar humerus fractures. *J Pediatr Orthop*. 2010;30(2):135-139. [CrossRef]
16. Yamamoto I, Ishii S, Usui M, Ogino T, Kaneda K. Cubitus varus deformity following supracondylar fracture of the humerus. A method for measuring rotational deformity. *Clin Orthop Relat Res*. 1985;201(201):179-185.
17. Abzug JM, Herman MJ. Management of supracondylar humerus fractures in children: current concepts. *J Am Acad Orthop Surg*. 2012;20(2):69-77. [CrossRef]
18. Sankar WN, Hebela NM, Skaggs DL, Flynn JM. Loss of pin fixation in displaced supracondylar humeral fractures in children: causes and prevention. *J Bone Joint Surg Am*. 2007;89(4):713-717. [CrossRef]
19. Jaeblon T, Anthony S, Ogden A, Andary JJ. Pediatric supracondylar fractures: variation in fracture patterns and the biomechanical effects of pin configuration. *J Pediatr Orthop*. 2016;36(8):787-792. [CrossRef]
20. Silva M, Knutsen AR, Kalma JJ, et al. Biomechanical testing of pin configurations in supracondylar humeral fractures: the effect of medial column comminution. *J Orthop Trauma*. 2013;27(5):275-280. [CrossRef]
21. Bloom T, Robertson C, Mahar AT, Newton P. Biomechanical analysis of supracondylar humerus fracture pinning for slightly malreduced fractures. *J Pediatr Orthop*. 2008;28(7):766-772. [CrossRef]
22. Herring JA. Tachdjian's Pediatric Orthopaedics. Vol. 3. 3rd ed. W.B. Saunders; Philadelphia; 2002:2153.
23. Skaggs DL, Hale JM, Bassett J, Kaminsky C, Kay RM, Tolo VT. Operative treatment of supracondylar fractures of the humerus in children: the consequences of pin placement. *J Bone Joint Surg Am*. 2001;83(5):735-740. [CrossRef]
24. Zhao JG, Wang J, Zhang P. Is lateral pin fixation for displaced supracondylar fractures of the humerus better than crossed pins in children?. *Clin Orthop Relat Res*. 2013;471(9):2942-2953. [CrossRef]
25. Slobogean BL, Jackman H, Tennant S, Slobogean GP, Mulpuri K. Iatrogenic ulnar nerve injury after the surgical treatment of displaced supracondylar fractures of the humerus: number needed to harm, a systematic review. *J Pediatr Orthop*. 2010;30(5):430-436. [CrossRef]
26. Rockwood CA, King RE, Kew Jr. Rockwood and Wilkins' Fractures in Children. Lippincott Williams & Wilkins; Philadelphia; 1990:596-605.