Observational Study

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Sagittal plane alignment affects the strength of pin fixation in supracondylar humerus fractures

Alexander M. Bitzer, MD, Stephen M. Belkoff, PhD, Christa L. LiBrizzi, BS, Chimelie Chibututu, BSc, R. Jay Lee, MD*

Abstract

Closed reduction with percutaneous pin fixation is commonly used to treat pediatric supracondylar humerus fractures. Various pin configurations of varying biomechanical strength have been described. However, to our knowledge, no biomechanical study has focused on pin alignment in the sagittal plane. Our goal was to compare the stability of fixation using 3 different pin constructs: 3 lateral pins diverging in the coronal plane but parallel in the sagittal plane (3LDP), 3 lateral pins diverging in the coronal and sagittal planes (3LDD), and 2 crossed pins (1 medial and 1 lateral).

Transverse fractures were made through the olecranon fossa of 48 synthetic humeri, which were then reduced and pinned in the 3LDP, 3LDD, and crossed-pin configurations (16 specimens per group) using 1.6-mm Kirschner wires. The sagittal plane pin spread was significantly greater in the 3LDD group than in the 3LDP group, whereas we found no difference in the coronal plane. Sagittal extension testing was performed from 0° to 20° at 1°/s for 10 cycles using a mechanical torque stand. The torque required to extend the distal fragment 20° from neutral was compared between groups using one-way analysis of variance with multiple comparison post-hoc analysis. P values $\leq .05$ were considered significant.

The 3LDD configuration was more stable than the 3LDP and crossed-pin configurations. The mean torque required to displace the pinned fractures was 5.7 Nm in the 3LDD group versus 4.1 Nm in the 3LDP group and 3.7 Nm in the crossed-pin group (both, $P < .01$). We found no difference in stability between the 3LDP and crossed-pin groups ($P = .45$).

In a synthetic biomechanical model of supracondylar humerus fracture, sagittal alignment influenced pin construct stability, and greater pin spread in the sagittal plane increased construct stability when using 3 lateral pins. The lateral pin configurations were superior in stability to the crossed-pin configuration.

Level of Evidence: Level V.

Abbreviations: 3LDD = 3 lateral pins diverging in the coronal and sagittal planes, 3LDP = 3 lateral pins diverging in the coronal plane but parallel in the sagittal plane, CRPP = closed reduction and percutaneous pinning, SCH = supracondylar humerus.

Keywords: closed reduction and percutaneous pinning, sagittal plane, supracondylar humerus fracture

1. Introduction

Supracondylar humerus (SCH) fractures are common injuries in children and adolescents, with an incidence of 60 to 72 per 100,000 children annually.[1] Many SCH fractures are treated with closed reduction and percutaneous pinning (CRPP) because this minimizes trauma to the soft tissues, is associated with few complications, and produces positive outcomes.[2–4]

Good outcomes after CRPP are achieved by recreating and maintaining a normal anterior humeral line and carrying angle in the sagittal and coronal planes, respectively.[5] Failure to restore or maintain coronal and sagittal plane alignment can lead to cubitus varus, which is primarily a cosmetic issue but can lead to pain, functional limitations, and delayed neuropathies.[5] Thus, it is imperative not only to reduce the fracture appropriately but also to maintain adequate sagittal and coronal alignment when using CRPP to treat SCH fractures.

Several types of pin construct have been studied to determine the fixation that best maintains appropriate alignment, resists deforming forces, and prevents a loss of reduction after CRPP. Surgeons must balance the goal of rigid fixation while respecting the soft-tissue envelope and minimizing complications. Biomechanical studies have shown increased construct stability with the use of larger pins, a capitellar starting point, and greater pin spread in the coronal plane.[6–9] However, similar studies have reported inconsistent results regarding the difference in strength between lateral-only configurations (whether with 2 or 3 pins) versus crossed-pin constructs.[7–10] Clinical studies show equivalent radiographic and functional outcomes for lateral-only and crossed-pin techniques.[11–13] However, the risk of iatrogenic injury to the ulnar nerve is higher when using the crossed-pin

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Division of Pediatric Surgery, Department of Orthopaedic Surgery, The Johns Hopkins University School of Medicine, Baltimore, Maryland.

* Correspondence: R. Jay Lee, Department of Orthopaedic Surgery, The Johns Hopkins Hospital, 1800 Orleans St, Baltimore, MD 21287 (e-mail: editorialservices@jhmi.edu).

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technique; thus, some surgeons prefer the lateral pinning technique.[14,15]

We tested whether a lateral pin construct with 3 pins could be optimized for rigidity by focusing on pin start point, spread, and configuration, not only in the coronal plane but also in the sagittal plane in a synthetic humerus model. Our goal was to compare the ability to resist an extension force placed on simulated supracondylar fractures pinned using 3 different configurations: 3 lateral pins diverging in the coronal plane but parallel in the sagittal plane (herein, “3LDP”), 3 lateral pins diverging in the coronal and sagittal planes (herein, “3LDD”), and 2 crossed pins (1 medial and 1 lateral). Our hypothesis was that the 3LDD pin configuration would provide greater stability in resisting an extension deformity compared with the 3LDP and 2 crossed pin constructs.

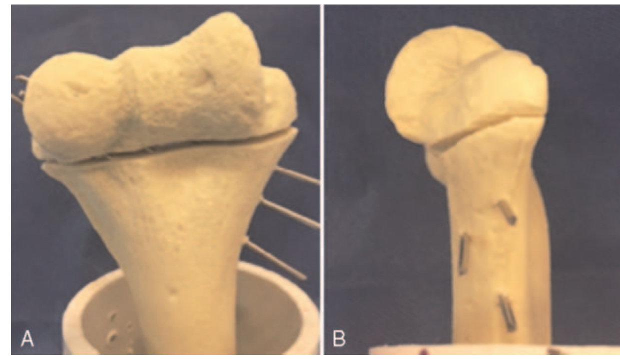

Figure 2. (A) Anteroposterior and (B) lateral photographs of 3 lateral pins diverging in coronal and sagittal planes in a synthetic humerus.

2. Methods

2.1. Model preparation

Ethical approval was not required for this study because this did not involve human research subjects.

We obtained 48 adult synthetic humeri (Sawbones #1019, Pacific Research Laboratories, Inc., Vashon Island, WA). The humeri were sectioned at the level of the mid-diaphysis, and the distal humeri were placed into a custom cutting jig consisting of a C-clamp to grasp the humeral shaft proximally. A distal femoral resection cutting guide from a total knee arthroplasty system (Persona; Zimmer Biomet, Warsaw, IN) was placed onto the distal humerus at the level of the proposed osteotomy to ensure consistency in fracture creation. Osteotomies were made using a fine blade sagittal saw and a cutting guide at the level of the mid-olecranon fossa. The created fractures were then reduced and assigned to the 3LDP, 3LDD, or crossed-pin groups for pinning configuration (16 specimens per group). After anatomic reduction, the specimens were pinned using 1.6-mm Kirschner wires (OrthoPediatrics Corp., Warsaw, IN) to produce 16 specimens with a 3LDP configuration (Fig. 1), 16 specimens with 3 lateral pins diverging in the coronal and sagittal planes (3LDD) (Fig. 2A), and 16 specimens with a crossed-pin configuration (Fig. 3). Pinning was performed using custom blocks with specified pin trajectories used to produce consistent pinning patterns for all 3 configurations. All of the lateral pins had a capitellar starting point. The 3LDP group starting points were collinear, whereas the 3LDD group starting points were not collinear but rather clustered in a triangular fashion, allowing divergence in the sagittal plane (Fig. 4). To prevent the 3LDD pins from being parallel in an oblique plane, we directed the most medial and most lateral pins posteriorly, whereas the central pin was directed anteriorly (Fig. 2B).

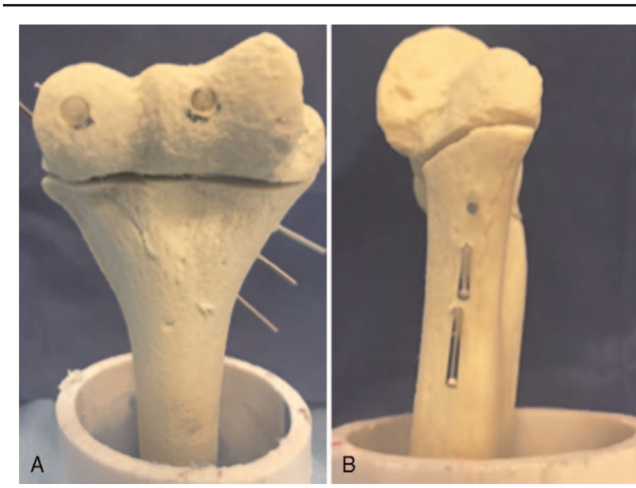

Figure 1. (A) Anteroposterior and (B) lateral photographs of 3 lateral pins diverging in coronal plane but parallel in sagittal plane in a synthetic humerus.

2.2. Biomechanical testing

After pin fixation, the diaphyseal portions were mounted onto a biaxial servohydraulic testing machine (MTS 858 Material Testing System, MTS Systems Corporation, Eden Prairie, MN). A torque was applied to the distal fragment to produce an extension-deforming vector on the distal fragment. The fragments were rotated from 0° to 20° of sagittal extension at 1°/s for 10 cycles. We then analyzed the torque required to rotate the distal fragment from 0° to 20°.

2.3. Statistical analysis

One-way analysis of variance was used to determine whether any significant difference existed in the torque (in Nm) required to rotate the distal fracture fragment from 0° to 20° of extension at 1°/s between the different sample groups. If a difference was

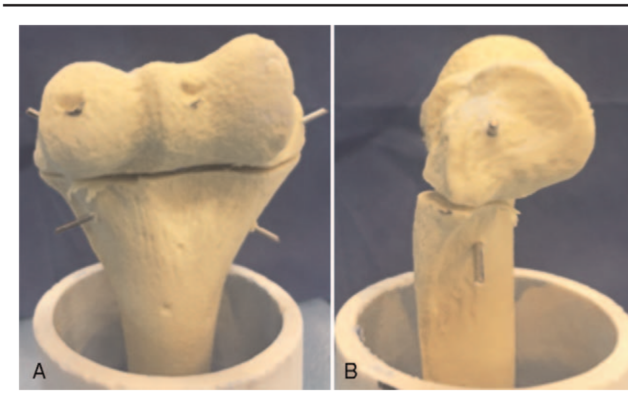

Figure 3. (A) Anteroposterior and (B) lateral photographs of a crossed-pin configuration in a synthetic humerus.

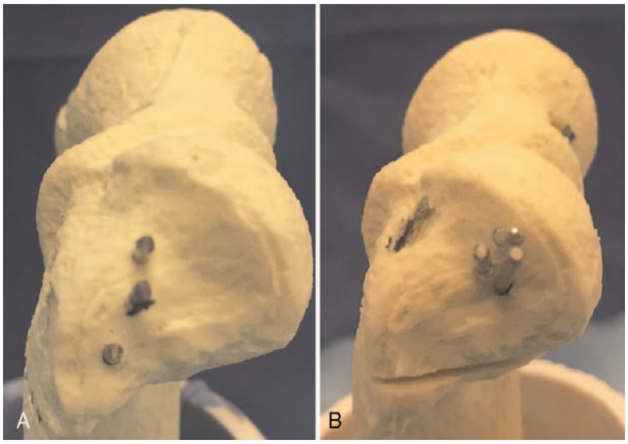

Figure 4. Lateral photographs of capitellar entry points in (A) 3LDP (3 lateral pins diverging in the coronal plane but parallel in the sagittal plane) versus (B) 3LDD (3 lateral pins diverging in the coronal and sagittal planes) configurations in a synthetic humerus. Note the parallel entry points in the 3LDP configuration versus the triangular starting points in the 3LDD configuration.

detected, a post-hoc analysis was performed using the Scheffe method to compare the means between groups. *P* values <.05 were considered significant. All analyses were performed using SPSS, versions 14.0 and 15.0, software (IBM Corp., Armonk, NY).

3. Results

The mean torque required to extend the distal fragment 20° from neutral was different among the 3 groups tested ($P<.01$). Post-hoc comparisons indicated that the mean torque required to achieve full displacement was significantly greater in the 3LDD configuration (5.7 Nm, 95% confidence interval [CI]: 5.3, 6.1) compared with both the 3LDP configuration (4.1 Nm, 95% CI: 3.4, 4.8) and the XP configuration (3.7 Nm, 95% CI: 3.3, 4.1) ($P<.01$). There was no significant difference in the mean torque required to achieve full displacement in the 3LDP configuration (4.1 Nm, 95% CI: 3.4, 4.8) versus the XP configuration (3.7 Nm, 95% CI: 3.3, 4.1) ($P=.45$). Figure 5 summarizes the relative construct stability between the different pin configurations from weakest to strongest.

The pin spread was recorded (in millimeters) between the 3 pins in the coronal and sagittal planes and was compared between groups. Coronal pin spread was measured as the entire distance from the most medial pin to the most lateral pin. Sagittal pin spread was measured as the distance between the most anterior and most posterior pin. The pin spread in the coronal plane was not significantly different in the 3LDP, 3LDD, or crossed-pin groups. The pin spread in the sagittal plane was significantly smaller in the 3LDP group (0.6 mm) than in the 3LDD group (6.5 mm) ($P<.001$). The overall pin spread between the 3LDD and 3LDP groups, accounting for coronal and sagittal plane pin spread, was compared by measuring the total area of a triangle created between the 3 pins used in each construct (Fig. 6). The total area of the configuration was significantly larger for the

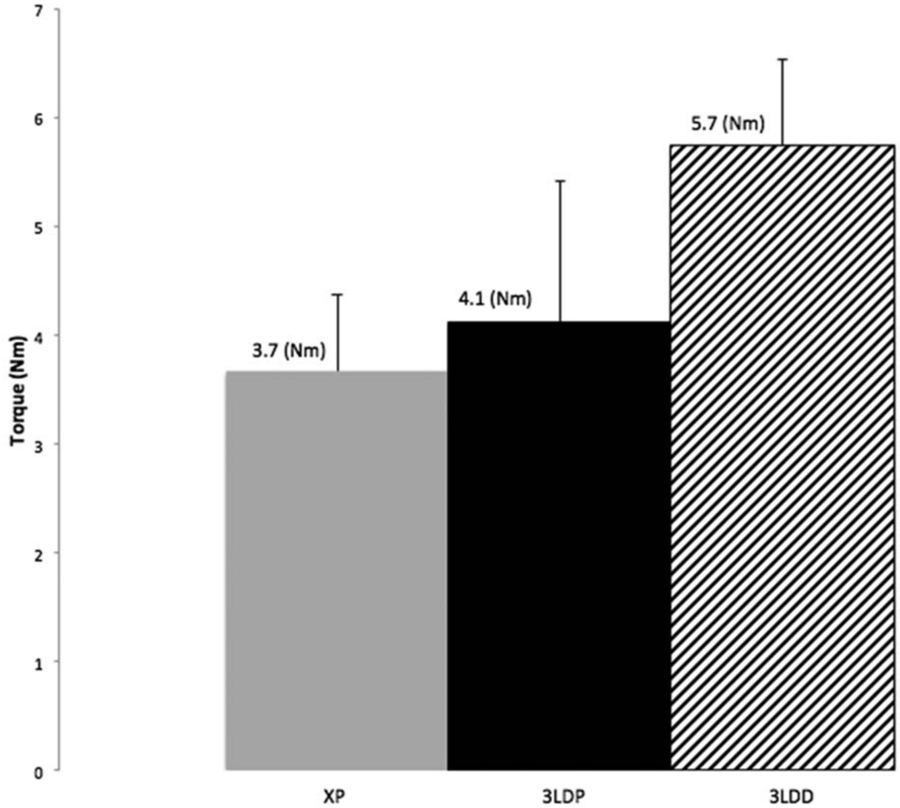

Figure 5. Mean torque (Nm) required to displace fracture fragment 20° from neutral in extension for each group (crossed pin [XP], 3LDP [3 lateral pins diverging in the coronal plane but parallel in the sagittal plane], and 3LDD [3 lateral pins diverging in the coronal and sagittal planes]). Error bars, standard deviation.

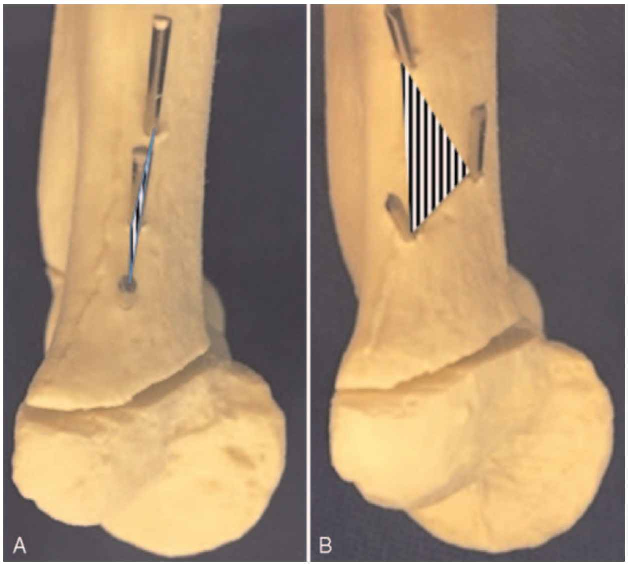

Figure 6. Lateral photographs of exiting pins in (A) 3LDP (3 lateral pins diverging in the coronal plane but parallel in the sagittal plane) and (B) 3LDD (3 lateral pins diverging in the coronal and sagittal planes) constructs in a synthetic humerus. Shaded areas represent the total triangular area of each configuration's general pin spread. The triangular area for the 3LDP configuration is smaller than that of the 3LDD configuration.

3LDD group (75 mm) than for the 3LDP group (6.8 mm) ($P < .001$).

4. Discussion

Operative treatment of pediatric SCH fractures frequently consists of CRPP. The 2 most common configurations are the crossed-pin construct and a 2- or 3-lateral pin construct with pin divergence in the coronal plane (3LDP). We found that during CRPP, pin divergence in the sagittal plane helps stabilize SCH fractures when using a 3-lateral pin construct.

One of the main reasons to perform lateral-only pinning versus crossed-pinning is to reduce the risk of iatrogenic ulnar nerve injury during placement of a medial pin. The incidence of iatrogenic ulnar nerve injury with medial pinning has been reported to be 0% to 9.4%.[11,13,16,17] Sahu[17] retrospectively analyzed 170 SCH fractures that underwent crossed-pin fixation or 2 lateral pin fixation. The incidence of postoperative ulnar neurapraxias was 9.4% in the crossed-pin group compared with 0% in the lateral pin group. Gaston et al[11] prospectively enrolled and randomized 104 patients with Gartland type-III SCH fractures (completely displaced apex anterior fracture without contact of the posterior cortex)[18] to lateral pin or crossed-pin constructs. They reported an incidence of postoperative ulnar neurapraxia of 3.5% in crossed pinning and 0% in lateral pinning. To avoid iatrogenic ulnar nerve injury during medial pin insertion, some surgeons have described palpation of the ulnar nerve over the skin, medial incisions for direct visualization of pin placement, or use of a more anterior starting pin position. Other options to avoid iatrogenic ulnar nerve injury are to avoid placing a medial pin altogether and to use only a 2– or 3–lateral pin fixation technique. One study that used a decision analysis model based on current evidence determined that lateral pinning was preferable to crossed-pinning given the concern for iatrogenic nerve injury.[14]

Other complications, such as cubitus varus and pin migration, have been reported after treatment of SCH fractures with CRPP. In a meta-analysis, Na et al[16] investigated the relationship between lateral-pin or crossed-pin fixation and the development of cubitus varus. Six studies were included in their model, which found a higher risk ratio for developing cubitus varus after lateral pin fixation (1.8 [95% confidence interval: 0.79, 4.1]) compared with crossed-pin fixation, but this difference was not significant. The same meta-analysis by Na et al[16] evaluated 8 studies on the loss of reduction via serial radiographic measurements of the Bauman angle. The authors found no significant difference in the rates of reduction loss in SCH fractures that used lateral pin constructs compared with crossed-pin constructs. Bashyal et al[19] studied complications after pinning of 622 pediatric SCH fractures and found that pin migration was the most common complication, with an incidence of 1.8%, which was most commonly seen in Gartland type-III fractures. However, they did not state which patients received lateral-pin versus crossed-pin constructs or whether pin migration was associated with construct type.

Studies of construct stability have found that crossed-pin configurations are more stable than 2–lateral pin constructs. Lee et al[8] tested the biomechanical properties of various pin constructs in the treatment of SCH fractures with synthetic humeri: 2 crossed pins; 2 lateral pins with coronal plane divergence; and 2 lateral pins parallel in the coronal plane. Crossed-pin constructs were significantly more stable in extension, internal rotation, and external rotation, as well as more stable compared with both lateral pin constructs. In a single-center, prospective randomized controlled trial, Abdel Karim et al[20] assigned 60 pediatric patients with operatively treated SCH fractures to receive either 2 lateral pin constructs or a 2 crossed-pin construct. The authors found a significantly higher rate of reduction loss when using 2 lateral pins (20%) compared with 2 crossed pins (0%) ($P = .031$). Contrary to these findings, a prospective randomized controlled trial by Maity et al[21] found no significant difference in stability (assessed radiographically) of SCH fractures treated with 2 lateral pins versus 2 crossed pins.

Biomechanical studies comparing the crossed-pin configuration with 3 lateral pins have reported varying results regarding construct strength.[9,10,22] Srikumaran et al[9] compared the stability of several pin constructs; 2 of which included the crossed-pin configuration and a 36–lateral pin configuration similar to the 3LDP group in our study. The crossed-pin group was more stable in extension testing compared with the 3LDP group, whereas we observed no significant difference in stability between the 3LDP and crossed-pin groups. One explanation for the discrepant findings may be unrecognized variance in coronal or sagittal pin spreads within or between test groups in the former study, which may have affected the respective group construct strength. Jaeblon et al[10] performed a biomechanical study to test the effects of various pin constructs and fracture patterns on stability using 90 pediatric synthetic bone models. They found that a 3–lateral pin construct, similar to our 3LDP model, was superior to the crossed-pin construct in varus/valgus and extension/flexion testing in low (relative to the olecranon fossa) fracture patterns and superior in rotational stability in high fracture patterns.[10] Our findings are consistent with this study, likely because of similarities in experimental design, including pin size, pinning technique, and fracture types tested. Additionally, the 3–lateral pin construct in the study by Jaeblon et al[10] may have benefited from increased stability secondary to subtle increases in sagittal plane spread between the 3 lateral pins, thus simulating a 3LDD construct, which, in our study, was even more stable than the 3LDP.

Our study has several limitations. First, it was a biomechanical study using adult synthetic humeri, which lack a soft-tissue envelope, have biomaterial properties distinct from bone, and are larger than pediatric humeri. A synthetic pediatric humerus model would have been more appropriate given the smaller area available in pediatric distal humeri compared with that of adults. However, we were able to achieve similar pin spread fixation using the same materials and methods in both adult and pediatric humeri during our model development phase. The distal humerus cross-sectional area available was sufficient to perform all 3 pin configurations (3LDD, 3LDP, crossed pin) in both the pediatric and adult synthetic humeri. In fact, the pediatric humerus model (Sawbones #1052, Pacific Research Laboratories, Inc.) is approximately 1 cm wide at its thinnest point in the sagittal plane and thus able to accommodate a 6.5-mm pin spread in the sagittal plane. Clinically, the senior author has been able to successfully treat pediatric patients using the 3LDD construct. However, concern remains regarding whether there is enough "real estate" to create sufficient spread in the sagittal plane, particularly in younger patients. One complication of the 3LDD technique is premature cortical breach, either anteriorly or posteriorly, when attempting to produce sufficient pin spread in the sagittal plane, where there is limited bony cross-sectional area. Unicortical fixation or premature cortical breach, where the pin is within only 1 of the 2 columns (medial and lateral), may lead to decreased fixation rigidity and potential harm to the surrounding soft tissues. Nevertheless, these complications can be avoided with appropriate pin placement and use of smaller diameter K-wires when creating the 3LDD construct.

Ultimately, we chose the adult humeri as our study model because of our previous experience with this model and the availability of the apparatus needed for appropriate processing and mechanical testing of study specimens. Thus, one cannot directly apply these results to a clinical setting. Second, we tested stability only in the sagittal extension plane and did not test axial, varus/valgus, or torsional stability. We chose to test stability in extension because a previous study showed this to be a common direction of displacement after CRPP.[9] However, the exclusive testing of construct stability using only a sagittal plane deforming vector allowed us to use identical specimens under similar experimental conditions, which helped provide consistent and precise results. Future biomechanical testing is needed to determine the significance of sagittal alignment in torsion and varus/valgus testing. Clinical studies are needed to ascertain patient functional outcomes, patient satisfaction, and complications of lateral pinning diverging in the sagittal and coronal planes compared with crossed-pin and 3LDP configurations.

5. Conclusions

Sagittal alignment and pin spread in the sagittal plane may affect pin construct rigidity when using 3 lateral pins for the treatment of pediatric SCH fractures. We found superior construct rigidity when using 3 lateral pins diverging in the coronal and sagittal planes compared with crossed-pin constructs and constructs with 3 lateral pins diverging only in the coronal plane.

Author contributions

Conceptualization: Stephen M. Belkoff, Christa L. LiBrizzi, R. Jay Lee, Alexander M. Bitzer.
Formal analysis: Alexander M. Bitzer.
Methodology: Alexander M. Bitzer, Stephen M. Belkoff, Chimelie Chibututu.
Writing – original draft: Alexander M. Bitzer, Christa L. LiBrizzi, Chimelie Chibututu, R. Jay Lee.
Writing – review & editing: R. Jay Lee, Alexander M. Bitzer, Christa L. LiBrizzi, Chimelie Chibututu, Stephen M. Belkoff.

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