Biomechanical Analysis of Pin Placement for Pediatric Supracondylar Humerus Fractures: Does Starting Point, Pin Size, and Number Matter?

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Background: Several studies have examined the biomechanical stability of smooth wire fixation constructs used to stabilize pediatric supracondylar humerus fractures. An analysis of varying pin size, number, and lateral starting points has not been performed previously.

Methods: Twenty synthetic humeri were sectioned in the mid-olecranon fossa to simulate a supracondylar humerus fracture. Specimens were all anatomically reduced and pinned with a lateral-entry configuration. There were 2 main groups based on specific lateral-entry starting point (direct lateral vs. capitellar). Within these groups pin size (1.6 vs. 2.0 mm) and number of pins (2 vs. 3) were varied and the specimens biomechanically tested. Each construct was tested in extension, varus, valgus, internal, and external rotation. Data for fragment stiffness (N/mm or N mm/degree) were analyzed with a multivariate analysis of variance and Bonferroni post hoc analysis ($P < 0.05$).

Results: The capitellar starting point provided for increased stiffness in internal and external rotation compared with a direct lateral starting point ($P < 0.05$). Two 2.0-mm pins were statistically superior to two 1.6-mm pins in internal and external rotation. There was no significant difference found comparing two versus three 1.6-mm pins.

Conclusions: The best torsional resistances were found in the capitellar starting group along with increased pin diameter. The capitellar starting point enables the surgeon to engage sufficient bone of the distal fragment and maximizes pin separation at the fracture site. In our anatomically reduced fracture model, the addition of a third pin provided no biomechanical advantage.

Clinical Relevance: Consider a capitellar starting point for the more distally placed pin in supracondylar humerus fractures, and if the patient's size allows, a larger pin construct will provide improved stiffness with regard to rotational stresses.

Key Words: supracondylar humerus fracture, pinning configuration, biomechanical analysis, lateral pinning

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Among fractures around the elbow joint in the pediatric population, supracondylar humerus fractures are the most common, representing approximately 65% of these fractures.[1] Historically, supracondylar humerus fractures were treated with a variety of methods such as closed reduction and splinting, traction, external fixation, and closed reduction with percutaneous pinning. Wilkins modified the Gartland classification, which is based on the amount of fracture displacement seen on x-ray.[2,3] Currently, the standard of care for most type II fractures and all type III fractures involves closed reduction with percutaneous pin fixation.[4] There continues to be debate regarding pin configuration (lateral entry vs. cross pin fixation) and number of pins for optimal stabilization.[1,5–13]

Because of the documented iatrogenic ulnar nerve injury from the medial cross pin (prevalence rate up to 12%),[7,11,12,14,15] there has been a predilection for placement of lateral divergent pins. Although recent biomechanical and clinical studies have supported the configuration of lateral smooth pin fixation[5,6,8,11]; there has been wide variation in the actual starting points. Some biomechanical studies have used a direct lateral, extra-articular starting point, almost directly on the lateral epicondyle,[5,6] whereas other studies have utilized a capitellar or paraolecranon starting point (Fig. 1).[8,11] This has previously been described by placing one of the lateral pins as close to midline as possible (just lateral to the olecranon).[16]

Skaggs et al[11] emphasized important technical points for fixation with lateral-entry pins, specifically maximizing the spread across the fracture site and engaging sufficient bone in both proximal and distal fragments. To our knowledge, no study has specifically addressed the actual starting points for the placement of lateral-entry pins. We retrospectively reviewed 110 cases of supracondylar fractures at our institution, and found that the most distal pin started within the cartilage anlage of the capitellum in 87 patients. The remaining 23 patients had a more direct lateral starting point (Gottschalk HP,

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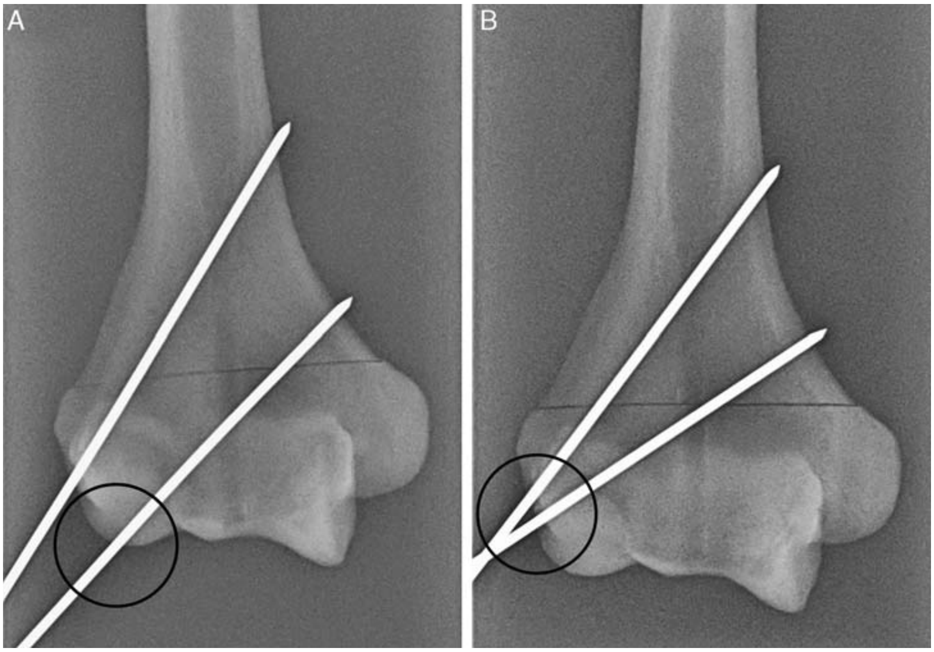

FIGURE 1. Starting points for lateral-entry pin fixation. A, The most distal pin starts within the cartilage anlage of the capitellum, or paraolecranon. B, The most distal pin starts extra-articular in a more direct lateral starting point.

Edmonds EW. unpublished data; Fig. 2). We therefore sought to address the question: does starting point in lateral-entry pinning influence the overall construct stiffness?

Despite the vast degree of research including biomechanical analysis on pin configuration, there is scant information comparing the size of the smooth pins used (1.6 vs. 2.0 mm smooth pin).[7,9] Traditionally, 1.6-mm smooth pins (0.062 inch) have been utilized for percutaneous pinning; however, recent literature has described the use of 2.0-mm smooth pins (5/64 inch).[7,10] Another goal of this study was to address the question: does the size of the smooth pin directly affect the construct stiffness?

Several studies have tauted the use of a third pin to aid in fracture stabilization.[5,8,11] Skaggs et al[11] recommended

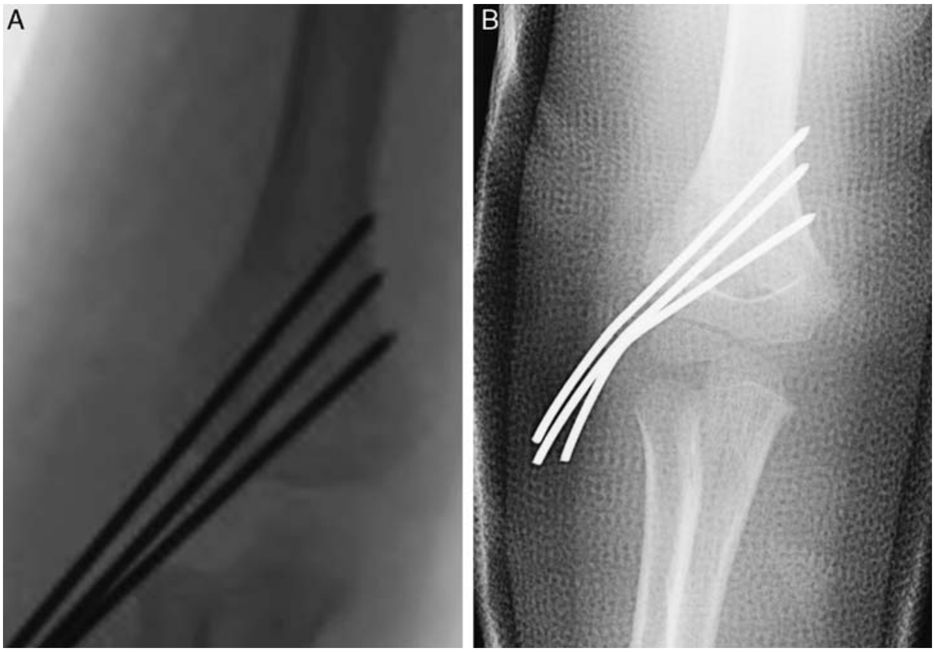

FIGURE 2. A, Antero-posterior (AP) radiograph demonstrating a capitellar starting point of the distal pin. B, AP radiograph demonstrating a direct lateral starting point.

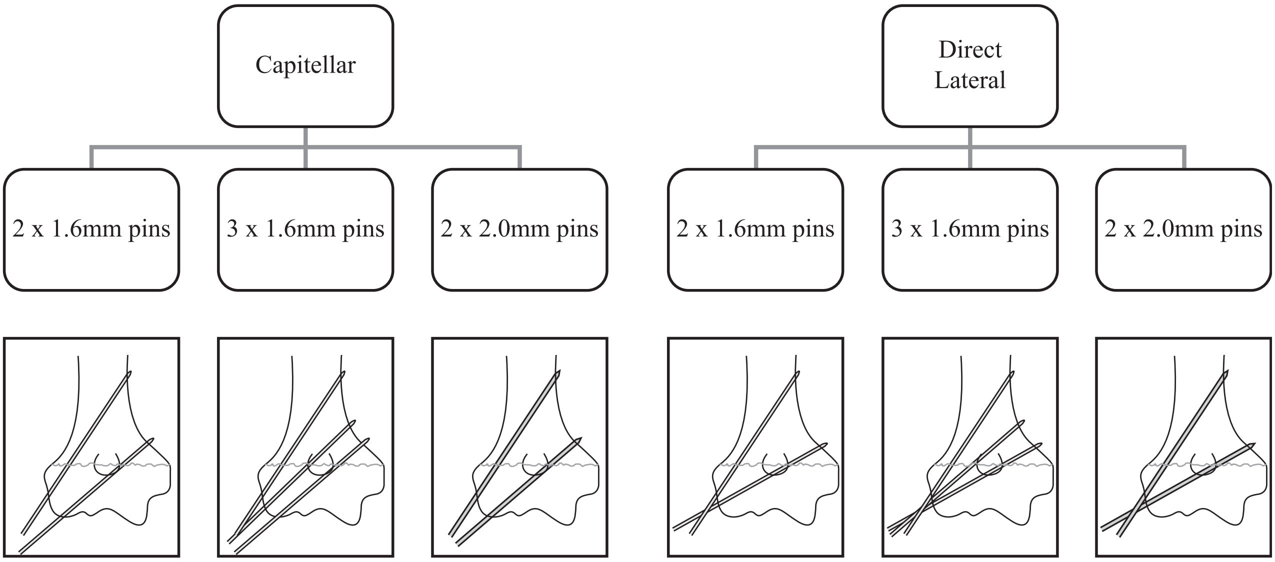

FIGURE 3. Schematic representation of various pin configurations used in this study.

using a third lateral pin if there was concern about fracture stability. Bloom et al[5] demonstrated that adding an additional third smooth pin would increase the construct stiffness in a malreduced fracture model. In the current study, an additional third smooth pin was added to a well-reduced, 2-pin construct to test the effect of pin number on construct stiffness. With these data, we would also be able to identify whether a 2 larger pin construct was equivalent or stiffer than a 3 smaller pin construct. The purpose of this study was to utilize a biomechanical model of a well-reduced distal humerus fracture to compare construct stiffness for pin-entry location, pin size, and number of pins.

METHODS

Biomechanical testing was performed on 20 synthetic humeri (Sawbones Model #1028, Pacific Research Laboratories, Vashon Island, WA). There were 2 main groups based on lateral-entry starting point: direct lateral versus capitellar (Fig. 3). Within each group, there were 3 different fixation types: two 1.6-mm pins, three 1.6-mm pins, and two 2.0-mm pins. To ensure consistency, all holes were predrilled using a 1.5-mm drill bit using a custom pin guide (Fig. 4). The trajectory of the lateral column pin was constant for all constructs. It started extra-articular and roughly paralleled the lateral metaphyseal flare of the humerus.[6] The most distal pin was placed so that it crossed the fracture site at the medial edge of the coronoid fossa.[6] In the capitellar group, the pin engaged the capitellum and simulated a "para-olecranon" starting point,[16] as would be done in a real patient. Once all pin trajectories were created, a cut was made through the olecranon fossa to simulate a transverse supracondylar humerus fracture. A custom-built jig and band saw was used to make the cuts, approximately 33 mm proximal to the distal most aspect of the trochlear point. The humeri were then anatomically reduced and fixated with 2 smooth pins; followed by a third pin after the initial testing, and then with the 2 larger pins.

After fracture stabilization, the humeral shafts were embedded in a 2-part epoxy resin (Bondo-Marhyde,

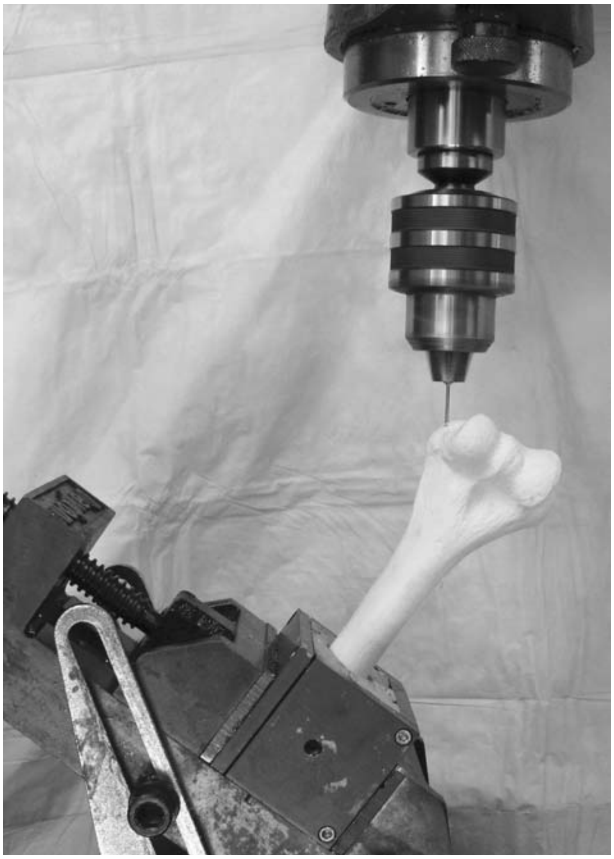

FIGURE 4. To ensure consistency, all holes were predrilled using a 1.5-mm drill bit and custom pin guide.

TABLE 1. Stiffness Data for Construct and Direction of Mechanical Loading

	Capitellar (2×1.6 mm)	Capitellar (3×1.6 mm)	Capitellar (2×2.0 mm)	Direct Lateral (2×1.6 mm)	Direct Lateral (3×1.6 mm)	Direct Lateral (2×2.0 mm)
Varus (N/mm)	12.7 ± 2.6	13.1 ± 3.6	16.9 ± 2.7	13.6 ± 2.7	12.4 ± 3.3	14.4 ± 3.5
Valgus (N/mm)	15.2 ± 3.6	15.5 ± 4.4	17.6 ± 5.4	16.4 ± 3.2	14.4 ± 5.7	14.0 ± 5.6
Extension (N/mm)	8.97 ± 1.8	9.34 ± 1.7	10.7 ± 1.6	11.3 ± 1.4	11.8 ± 1.5	12.7 ± 2.4
Internal rotation (N mm/degree)	309 ± 10	321 ± 20	369 ± 30	239 ± 37	233 ± 30	318 ± 53
External rotation (N mm/degree)	324 ± 18	342 ± 19	380 ± 17	243 ± 46	254 ± 40	346 ± 38

Values are mean ± SD.

Atlanta, GA) and secured with custom fixation rigs to a biaxial servohydraulic MTS858 test frame (MTS Co., Eden Prairie, MN). The stability of the distal fragment was then evaluated by conducting mechanical testing in varus, valgus, extension, internal rotation, and external rotation. For extension, varus, and valgus, constructs were tested by applying a translational force through the distal fragment at 0.5 mm/s to a maximum of 4 mm of displacement. For internal and external rotation, constructs were tested at 0.5 degrees/s to an end point of 10 degrees, respectively. Data for displacement (mm), force (N), rotation (degrees), and torque (N/mm) were sampled at 10 Hz during every test. Data for stiffness (N/mm or N m/degree) was calculated from the loading phase of the last 2 cycles of each test and compared.

All data were analyzed using MATLAB custom biomechanical application. From the processed data, the following parameters were extracted and served as dependent variables: stiffness in flexion/extension, internal/external rotation, and varus/valgus. A multivariate analysis of variance was used to evaluate the influence of pin diameter on these parameters. Statistical significance was determined using a P value of 0.05.

RESULTS

The construct stiffness data are presented in Table 1.

Starting Point

The capitellar starting point had a stiffer construct compared with the direct lateral construct in internal and external rotation ($P = 0.0001$ for both; Fig. 5). There was no statistical difference in varus, valgus, or extension.

Size of Pin

The 2.0-mm pins had a stiffer construct than the 1.6-mm pins in internal and external rotation in the direct lateral group ($P = 0.0001$; Fig. 6). There was no statistical difference noted in varus, valgus, or extension. However, in the capitellar starting point group, the 2.0-mm pins were stiffer than the 1.6-mm pins in varus, internal, and external rotation ($P = 0.031$, 0.0001, 0.0001, respectively). There was no statistical difference noted in valgus or extension.

Number of Pins

With respect to the number of pins (two 1.6-mm pins vs. three 1.6-mm pins), no differences were noted in any of the modes of stress in either the direct lateral or capitellar starting point groups. When comparing two 2.0-mm pins versus three 1.6-mm pins, the 2.0-mm pin construct was stiffer in internal and external rotation utilizing either of the 2 starting point groups ($P = 0.0001$; Fig. 7). There was no statistical difference noted in varus, valgus, or extension.

DISCUSSION

The gold standard for displaced supracondylar humerus fractures is in close reduction with percutaneous pinning. The goals of treatment are to provide anatomic reduction, stability, and prevent postoperative deformity including cubitus varus.[4] Controversy remains around the exact pin configuration. Zionts et al[17] demonstrated that

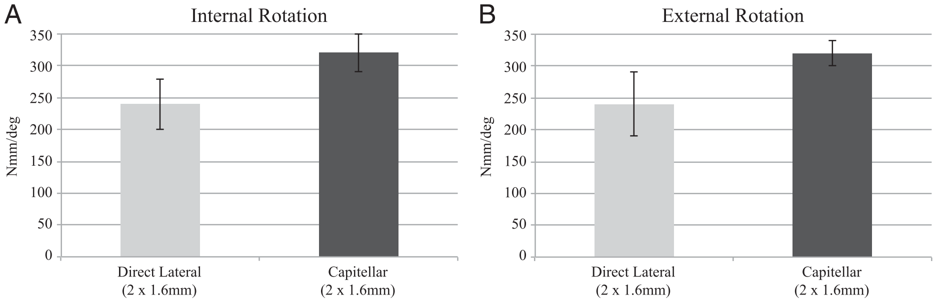

FIGURE 5. Torsional stiffness (N mm/degree) between starting points (direct lateral vs. capitellar) internal rotation (A) and external rotation (B) ($P < 0.0001$).

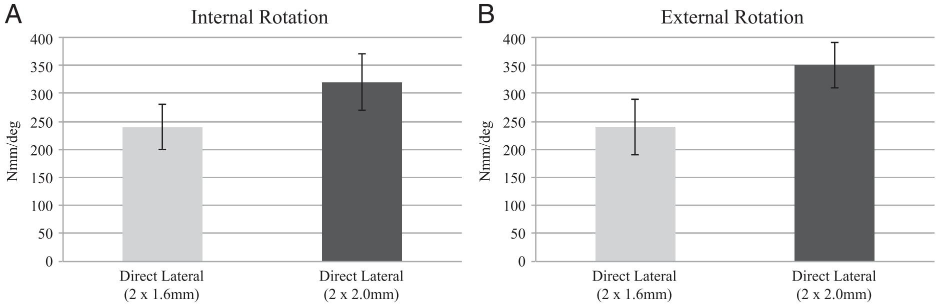

FIGURE 6. Torsional stiffness (N mm/degree) comparing 1.6-mm pin construct versus 2.0-mm pin construct in direct lateral starting group. A, Internal rotation. B, External rotation ($P < 0.0001$).

the most stable configuration to torque resistance is a crossed pin technique. This was noted to be 25% more rigid than the 3 lateral pins but was not statistically significant. However, the crossed pins were 37% stronger than the 2 lateral parallel pins and 80% stronger than the 2 lateral pins crossing at the fracture site ($P < 0.05$ for both comparisons). Although cross pins seem to provide additional torsional stability, the incidence of an ulnar nerve injury ranges from 1% to 12%.[8,11,18–20] This has led most surgeons to use only lateral-entry starting points. Recent literature has supported the use of lateral-entry pins both clinically and biomechanically.[4–6,8,10–12,21] However, little has been documented with regard to exact starting points on the lateral side.

Effect of Starting Point on Fracture Stability

Several biomechanical studies have illustrations depicting a direct lateral starting point, staying extra-articular with all pins.[5,6] Other studies and texts have shown a more paraolecranon or capitellar starting point for their most distal pins.[8,16,21] Our study showed an increase in construct stiffness with a more capitellar starting point with regard to internal and external rotation. By starting within the capitellar anlage, several advantages are provided: (1) ability to engage sufficient bone of the distal fragment, (2) maximize separation of the pins at the fracture site, and (3) allow sufficient room for the placement of a third lateral pin, if warranted. Anecdotally, we looked at 110 cases of displaced type III supracondylar humerus fractures over the last 2 years, to see whether there was a pattern in lateral entry starting points. In 79% of the cases, the most distal pin was placed within the capitellar anlage/capitellum. At our institution, this pin is supplemented with a lateral column pin (usually starting extra-articular on the lateral side) and for type III fractures, a third pin is routinely added. Because the most distal pin communicates with the joint, all pins are removed at 3 weeks, and the child is allowed to start range of motion at that time.

Effect of Number of Pins on Fracture Stability

Proper pinning technique and understanding of the fracture pattern is required to avoid failures. Sankar et al[22] reported 7 cases of failed fixation using lateral-entry pins; 4 due to only 1 pin in the distal fragment, 2 with inadequate pin separation at the fracture site, and 1 with no bicortical purchase. They did not report whether there was an anatomic reduction versus a slightly malreduced fracture. Bloom et al[5] performed a biomechanical study on fracture pinning in slightly malreduced fractures. He concluded that anatomically reduced fractures can be treated with 2 pins; however, an additional third pin is prudent for slightly internally rotated fractures to improve stability and prevent additional loss of reduction. The current study supports this conclusion; we observed no difference in construct stiffness with regard to the number of pins placed. We were able to achieve an anatomic reduction in each sawbone model secondary to predrilling of the pin tracts before cutting the bone.

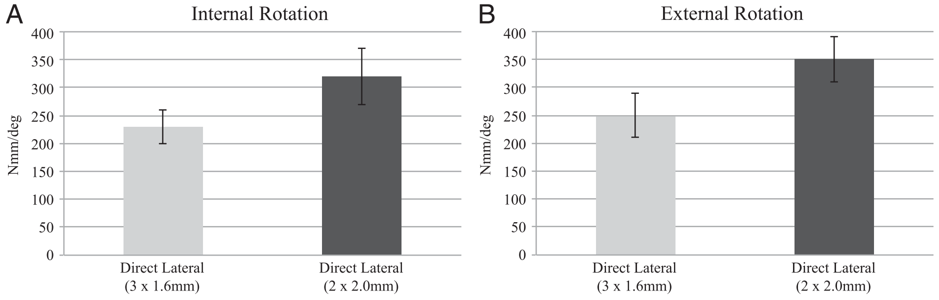

FIGURE 7. Torsional stiffness (N mm/degree) between a 2 × 2.0 mm pin construct versus a 3 × 1.6-mm pin construct in direct lateral starting group. A, Internal rotation. B, External rotation ($P < 0.0001$).

Certain fracture patterns are inherently more unstable than others. Larson et al[8] performed a biomechanical study showing a reduction in torsional stability when medial column comminution was present. In this fracture type, additional fixation may be warranted; either a medial pin or a third lateral pin.[6,8]

Effect of Pin Size on Fracture Stability

There is also limited information on pin size relating to stability of supracondylar humerus fractures. Many of the past biomechanical studies have used 1.6-mm pins for fixation[5,6,8]; compared with clinical studies that have utilized 2.0-mm pins for stabilization.[7,21,23] Most recently, Srikumaran et al[23] performed a retrospective study to analyze the efficacy of pin size on fracture stabilization in the sagittal plane. They defined their pin size group based on the ratio of pin diameter to cortical thickness; small if the ratio was ≤ 0.9 and large if the ratio was > 0.9. The pin sizes ranged from 0.9 to 3.6 mm (the most commonly used pins being 1.6 and 2.8 mm). They concluded from their study that the large pin size group had significantly greater maintenance of sagittal alignment at final follow-up than the small pin size group.[23] The current study demonstrated that the 2.0-mm pin construct was stiffer than the 1.6 mm configuration with regard to varus, internal, and external rotation, $P < 0.05$, but no difference in extension. In addition, we showed that two 2.0-mm pins placed through a direct lateral starting point were equivalent to three 1.6-mm pins (capitellar starting point) and better than three 1.6-mm pins (direct lateral) with regard to internal and external rotation. This trend was similar in the capitellar starting group.

It makes sense that larger pins would provide more stability, but not every patient requires bigger pins. Kocher et al[7] used body weight to determine whether to use 1.6-mm pins versus 2.0-mm pins. If the patient weighed ≤ 20 kg, then 1.6-mm pins were used; and if the patient weighed > 20 kg, then 2.0-mm pins were selected. Srikumaran et al[23] determined the pin size by the ratio of the diameter of the pin to the patient's humeral midshaft cortical thickness; for a "large" pin the ratio should be > 1.

Some limitations to the current study must be acknowledged. Although the use of synthetic models for biomechanical testing of fracture reduction techniques is common in the literature,[5,8,9,24,25] these studies cannot account for variability in supracondylar humerus fractures, nor the surrounding soft tissue anatomy, that may contribute to additional stability. Another limitation is that the individual modes of stress applied to the synthetic sawbone models do not mimic the in vivo physiologic stress that is applied to the elbow. Cadaver tissue is expensive and usually presents with varying bone quality. Synthetic bones are a good alternative and are well accepted for use in implant testing studies.[26] They are homogenous and of equal quality so that the only variation presented is in the implant configuration which is the primary interest. Although the sawbone models are adult size, the aim of the study is to compare different entry points, different pin configurations, and varying pin numbers. In such a comparative study, the size of the testing medium will not change the relative results but only the absolute magnitudes. In other words, the stiffness of each construct will increase proportionally so that the final differences between the configurations and their statistical power will not be influenced. Despite these limitations, the study does provide information that can be compared with prior studies regarding stability of pin constructs.

According to our data, diverging lateral-entry pins with 1 pin in the lateral column and another pin starting in the capitellum anlage (capitellar starting point) will provide greater construct stiffness in internal and external rotation. This maximizes the pin distance at the fracture site and allows for the axis of rotation to be moved further away from the fracture site, imparting increased stiffness to the construct. In addition, obtaining an anatomical reduction in the axial plane maximizes stability, and allows for the use of only 2 pins. If the patient's size allows, a larger pin construct will provide improved stiffness with regard to rotational forces. If there is hesitation in placing a pin through the capitellum, then a two 2.0-mm pin (direct lateral) construct was shown to be more stable than any of the three 1.6-mm pin configurations (direct lateral or capitellar starting points).

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