Biomechanical analysis of four external fixation pin insertion techniques

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Abstract

Having multiple external fixation pin designs and insertion techniques has led to debate as to which combination creates the stiffest construct. This study sought to biomechanically evaluate construct strength using self-drilling (SD) and self-tapping (ST) pins inserted with either bicortical or unicortical fixation. SD and ST 5.0 mm stainless steel pins were used in combination with bicortical self-drilling (BCSD), bicortical self-tapping (BCST), unicortical self-drilling (UCSD), and unicortical self-tapping (UCST) techniques. Pre-drilling for the self-tapping pins was completed with a 4.0 mm drill bit using ¾ inch polyvinyl chloride (PVC) pipe as the insertional medium. The PVC pin constructs were then loaded to failure in a cantilever bending method using a mechanical testing system. Ten trials of each technique were analyzed. BCSD insertion technique had the highest maximum failure force and stiffness of all tested techniques (P<0.0001). SD pins were significantly stronger to bending forces than ST pins in both the unicortical and bicortical setting (P<0.0001). Three point bending tests of the 5.0 mm SD and ST threaded area showed that threaded portion of the SD pins had a 300 N greater maximum failure force than the ST pins. Biomechanical analysis of external fixation pin insertion techniques demonstrates that bicortical fixation with SD pins achieved the greatest resistance to bending load. Despite both pins being 5.0 mm and constructed from stainless steel, ST and SD behaved differently with regard to maximum failure force and stiffness. This study demonstrates that insertion technique and pin selection are both important variables when attempting to achieve a stiff external fixation construct.

Introduction

External fixation is a temporizing, and at times definitive, fixation method used in a wide array of orthopaedic scenarios. Consisting of pins, connecting bars and clamps, this construct can be rapidly applied with minimal insult to surrounding soft tissues.⁵,⁶ External fixation constructs have evolved to include a multitude of applications and forms, yet the main principles that affect the overall stability of the construct remain the same. Factors affecting stability include pin number/size/placement, the distance between the bone and connecting rods, the number of connecting rods, and the pin to bone interface.⁴,⁵,⁶

While many factors affect the stability of external fixators, the pin-bone interface has been noted to be the most important in determining both long-term strength and survivability of the construct.⁷ This interface depends on the bone quality, pin design, and insertion technique. While the quality of the bone is not controlled by the surgeon, the insertion technique and pin selection are modifiable variables that affect the stability and longevity of an external fixation frame.⁸,⁹ The insertion technique is influenced by pin design with the two most common pin types being SD and ST pins. These half threaded pins include built-in taps and flutes to allow for egress of bone dust. SD and ST pins can decrease operative time allowing for a single insertion which bypasses the need for pre-drilling or tapping. Non SD and non-ST pins require pre-drilling or pre-tapping before final pin insertion.

Pin insertion technique is one of the most important biomechanical principles to maximize the pin-bone interface and help prevent pin loosening.³ With the existence of multiple pin insertion techniques and no standardized insertion method, there has been debate as to which technique creates the stiffest construct. Current concern focuses on the theoretical increased risk of loosening with bicortical pin fixation. The suggested mechanism of loosening occurs after the near cortical hole is drilled. As the pin engages the second cortex and begins drilling the far cortex, the near cortical hole enlarges due to threads constantly spinning until the far cortex is engaged with the pin threads. This results in the far cortex being the only site of thread engagement, which may potentially increase the risk for pin loosening.⁴⁻¹¹ To prevent this, some surgeons advocate for engaging the tip of the half threaded pin in the far cortex without over drilling the near cortex threads. Arbeitsgemeinschaft für Osteosynthesefragen (AO Trauma Foundation) recommends an external fixation pin be placed with minimal purchase in the far cortex when constructing an external fixation frame.¹²

The aim of this biomechanical study was to evaluate construct stiffness using SD and ST pins that were inserted with either bicortical or unicortical fixation. To the authors’ knowledge, this study is the first to biomechanically evaluate pin insertion techniques for one of the oldest and most common forms of orthopaedic fracture fixation.

Materials and Methods

Four insertion techniques were evaluated with the use of stainless steel, 150 mm x 5.0 mm SD and ST pins (Zimmer Warsaw, IN, USA): Bicortical self-drilling (BCSD), bicortical self-tapping (BCST), unicortical self-drilling (UCSD), and unicortical self-tapping (UCST). ST pin pre-drilling was completed with a 4.0 mm drill bit and ¾ inch PVC pipe was the insertional medium. PVC eliminated the variability of bone quality and diameter variations between cadaveric specimens. UC fixation was achieved when the fluted pin tip abutted the far cortex, while bicortical fixation demon-
Stratified thread engagement of both cortices (Figure 1). Precise BC and UC positioning were confirmed via direct visual inspection with span length set at 5 cm (Figure 2). Prior to loading the PVC/pin constructs, the bottom portion of the PVC pipe was firmly secured or potted using Cerrobend alloy. The PVC – external pin constructs were then tested in a cantilever bending mode at a loading rate of 5 mm/min using a mechanical testing system (800L Dynamic Test System, Test Resources Inc., MN, USA) (Figure 3). The constructs were loaded to failure. Ten trials of each insertional technique were recorded and analyzed. A new pin was used for each trial.

Failure was defined once the maximum failure force for each specimen was achieved. The stiffness for each trial was determined by calculating the maximum slope at the linear region of the load-displacement curve using a LabVIEW (National Instruments Corporation, TX, USA) program. Statistical analysis was performed using ANOVA.

Results

The BCSD insertion technique demonstrated the highest maximum failure force (Mean: 816.0 N) and stiffness (Mean: 163.13 N/m) compared to all other insertion techniques (P<0.0001) (Figures 4 and 5). SD pins were significantly stronger to bending forces compared to ST pins inserted with the same techniques (P<0.0001). BCSD pins had a 72% increase in maximum failure force compared to UCSD pins (P<0.0001). BCST were 82% stronger when compared to UCST (P<0.0001).

Three point bending tests of the SD and ST pins showed that despite both pins being 5.0 mm and composed of stainless steel, SD pins had an average maximum failure force (1302.0N) greater than 300 N higher than the 5.0 mm self-tapping pins (998.1N) (Figure 6).

Discussion

The external fixator has been in existence for over a century and is utilized in many clinical situations in orthopedics as a form of temporary and definitive fracture fixation. Pin to bone interface is a major contributor to the stability of an external fixator, therefore maximizing this variable is a vital component to construct viability. Bone quality and pin insertion techniques both contribute in creating a stable pin to bone interface. Critics of bicortical pin fixation argue that the near cortex thread purchase can be damaged as the drill bit engages the far cortex. As the tip spins to...
cut the far cortex, the bone threads in the near cortex are stripped, thus diminishing mechanical integrity.\textsuperscript{13} Concerns also exist in that a bicortical pin can damage neurovascular structures that lie beyond the far cortex if the pin penetrates too deeply. unicortical fixation would prevent both of these pin insertion complications. As multiple recommendations for pin insertion exist, this study examined various techniques to determine which pin type and insertion method created the greatest stability under a bending load.

Previous biomechanical studies have evaluated various components of external fixation. Seitz et al demonstrated that increasing pin diameter and the number of pins is an important factor in fixator stability.\textsuperscript{14} Increasing the number of connecting bars and decreasing their distance from the bone has also been shown to increase the rigidity of an external fixator.\textsuperscript{5} Although each external fixation component plays a role in creating stability, the pin to bone interface is crucial for construct stiffness and stability. The recognition of the importance of this interface has led to continued pin research and is exemplified with the development of hydroxyapatite coated pins. These pins have shown to increase fixation pullout strength compared to uncoated pins.\textsuperscript{13,16} This study demonstrates yet another biomechanical principle of pin insertion which increases the fixation at the pin/bone interface. BC fixation with SD pins led to significantly increased stiffness and maximum failure force when placed under a bending moment compared to UCSD, UCST or BCST techniques. Although all SD and ST pins were composed of stainless steel and measured 150mm x 5.0 mm, three point bending tests demonstrated that SD pins are roughly 30% stronger at resisting a bending force. This can be attributed to the different thread designs inherent in ST and SD pins. The minor diameter of the ST pin is 4.2 mm, while the minor diameter of a SD pin is 4.4 mm. Although a subtle 0.2 mm difference, the bending strength of a cylinder is radius to the fourth power. Therefore, a small change in the minor diameter results in a dramatic change in biomechanical properties. When selecting an external fixation pin, a surgeon may not realize the difference in minor diameters between ST and SD pin designs, which can affect the overall construct strength.

Limitations to our study include the use of PVC pipe. Though its use minimized the variability of differing bone qualities between tests, future studies should focus on standardized ex vivo bone samples or in vivo animal studies. This study evaluated the bending strength of the external fixation pins rather than pin pullout. Although previous studies evaluated pin pullout strengths, this is not a common mode of failure for external fixation devices. Since failure is commonly caused by bending fatigue at the pin bone interface, our study provides a more accurate assessment of clinical failure through a bending force. Another limitation was the variation in inherent pin strengths. To control for inherent pin differences between the SD and ST pins, an additional ten trials of SD pins were inserted using the bicortical/self-tapping technique. These pre-drilled SDBC were loaded to failure and compared to the original SDBC yield strength data (816.0 N). The pre-drilled SDBC pins had an average yield strength of 829.2 N, a result which was not statistically significant compared to the SDBC data (P=0.892). This result demonstrates that the insertion of a pin without pre-drilling had no significant effect on the pin in regard to force to failure or stiffness.

Conclusions

Determining the strongest insertion technique through biomechanical analysis provides objective data to maximize construct stability. The biomechanical performance of BC pin fixation demonstrates a significant increase in maximum failure force and stiffness compared to unicortical fixation. Although this may seem intuitive, controversy over pin insertion techniques still exists and no standardized pin insertion technique has been described. BC pin fixation with SD pins increases the pin to bone interface strength, which may result in a decrease in pin loosening and an improvement in clinical outcomes. With proper knowledge of surrounding anatomical structures and intraoperative imaging, BC fixation provides the greatest strength and stiffness for an external fixation device. Adherence to BC pin insertion with SD pins may improve stability and longevity in external fixation constructs.

References