In vitro comparison of the use of two large-animal, centrally threaded, positive-profile transfixation pin designs in the equine third metacarpal bone

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**Objective**—To compare the in vitro holding power and associated microstructural damage of 2 large-animal centrally threaded positive-profile transfixation pins in the diaphysis of the equine third metacarpal bone.

**Sample Population**—25 pairs of adult equine metacarpal bones.

**Procedure**—Centrally threaded positive-profile transfixation pins of 2 different designs (ie, self-drilling, self-tapping [SDST] vs nonself-drilling, nonself-tapping [NDNT] transfixation pins) were inserted into the middiaphysis of adult equine metacarpal bones. Temperature of the hardware was measured during each step of insertion with a surface thermocouple. Bone and cortical width, transfixation pin placement, and cortical damage were assessed radiographically. Resistance to axial extraction before and after cyclic loading was measured using a material testing system. Microstructural damage caused by transfixation pin insertion was evaluated by scanning electron microscopy.

**Results**—The temperature following pin insertion was significantly higher for SDST transfixation pins. Periosteal surface cortical fractures were found in 50% of the bones with SDST transfixation pins and in none with NDNT transfixation pins. The NDNT transfixation pins were significantly more resistant to axial extraction than SDST transfixation pins. Grossly and microscopically, NDNT transfixation pins created less damage to the bone and a more consistent thread pattern.

**Conclusions and Clinical Relevance**—In vitro analysis revealed that insertion of NDNT transfixation pins cause less macroscopic and microscopic damage to the bone than SDST transfixation pins. The NDNT transfixation pins have a greater pull out strength, reflecting better initial bone transfixation pin stability. (Am J Vet Res 2000;61:1298–1303)

External skeletal fixation (ESF) has been used in human and small animal orthopedic surgery for the stabilization of fractures that are highly comminuted, have an absolute bone loss, have severe soft tissue damage, or are open and infected. In equine orthopedic surgery, these fractures are also candidates for ESF. Other uses of ESF in horses include suspensory apparatus failure, joint luxation, facilitated ankylosis, and diversion of the forces of weightbearing from internal fixation. External skeletal fixation can provide stability without surgical invasion of the fracture site, minimizing soft tissue and vascular disruption and decreasing the chance of infection. These characteristics make ESF an important method of fracture repair for complicated equine fractures.

Small animal and human external skeletal fixators are not capable of withstanding the force of weightbearing by mature large animals; therefore, alternative fixator designs have been developed. Two main types of fixators are currently used in large animals—the transfixation cast and the lower limb external fixator. Both fixation modalities use transcutaneous, osseous transfixation pins, proximal to the fracture, connected to an external frame consisting of a fiberglass cast or sidebars attached to a footprint. This allows weight to be transferred from the bone to the transfixation pins and the cast or fixator down to the ground.

The maintenance of rigid fracture stabilization with ESF relies on the structural and functional integrity of the components and their interfaces. Historically, the clamps that attach transfixation pins to the sidebars were strength-limiting. The transfixation cast and external fixator have eliminated the clamps from the design used in horses. These fixators provide a rigid fixation capable of withstanding weightbearing of the adult animal. Therefore, the bone-pin interface (BPI) is the strength-limiting component of the ESF in horses. Failure at the BPI manifests itself by premature transfixation pin loosening and transfixation pin tract infection, ultimately causing loss of stability at the fracture site. Premature transfixation pin loosening at the BPI is the most common complication associated with the use of ESF. Transfixation pin loosening is the result of a complex interaction between biological and mechanical factors. These factors include transfixation pin design, material properties of the implant, rigidity of the fixator, transfixation pin insertion technique, location of the transfixation pins in the bone, cyclic loading, bone quality and quantity, and the osseous response to transfixation pin implantation and loading. Transfixation pin loosening is associated with signs of pain, loss of fracture stability, transfixation pin tract sepsis, predisposition to the development of a secondary fracture through the bone at the BPI interface, and the need for additional surgery.

Proper insertion technique is a prerequisite for long-term maintenance of transfixation pins. Vascular
injuries and thermal necrosis that may develop during transfixation pin insertion affect the long-term stability of the fixator. Delayed death of osteocytes, not seen until 3 weeks or more after injury, occurs at 47 C.19 Exposure to a temperature of 47 C for 1 minute causes bone resorption.19 High speed drilling, poor elimination of kerf that increases friction, and direct transfixation pin insertion without predrilling have all been associated with an increase in thermal necrosis.20,21 Thermal necrosis will contribute to transfixation pin loosening and infection of the transfixation pin tract by causing bone resorption and ring sequestration.21

Microfractures created by transfixation pin insertion contribute to premature transfixation pin loosening.12-14 Transfixation pin design is 1 of the determinants of the amount of damage that occurs to the bone during insertion.22 The microdamage created by the insertion technique will be propagated by cyclic loading.23,24 Motion between the implant and the bone during cyclic loading may increase osteoclast activity, which will further contribute to transfixation pin loosening.21 The cycle of transfixation pin loosening and osteolysis at the BPI results in progressive cortical bone loss. As the cortical defect enlarges, there is an increased risk of catastrophic failure.25

Pin design and insertion techniques are important in maintaining a solid BPI, measured in vitro as holding power.3,27 Nonthreaded transfixation pins have poor holding power and a tendency to loosen during repeated cyclic loading.21 Threaded transfixation pins have a high pull-out strength but are weakened by stress concentration at the threaded-nonthreaded interface.21 This stress concentration is eliminated in positive-profile threaded transfixation pins.21 They are designed to increase the holding power of the transfixation pin without compromising the internal diameter of the transfixation pin shaft, thus taking advantage of the holding power of a threaded transfixation pin without predisposing it to breakage.

Pin design and insertion technique have been extensively studied in human and small-animal surgery.4-5,25-28 Until recently, the use of ESF in large animals was based on knowledge acquired from other species. Two fairly new types of positive-profile threaded transfixation pins are now available for use in mature large animals. Both of these transfixation pins have a 6.3-mm core diameter but differ in design and insertion technique. We hypothesize that self-drilling, self-tapping (SDST) transfixation pins will cause more damage to the BPI than separate steps of drilling, tapping, and transfixation pin placement (ie, nonself-drilling, nonself-tapping [NDNT] transfixation pins). The specific aims of the study reported here were to compare the in vitro holding power and associated microstructural damage of 2 large-animal, centrally threaded, positive-profile transfixation pins in the diaphysis of the equine third metacarpal bone. Comparisons in damage caused by transfixation pin insertion between SDST and NDNT transfixation pins were made on the basis of temperature, radiographic changes, resistance to extraction, and findings on scanning electron micrographs.

**Materials and Methods**

Two centrally threaded positive-profile transfixation pins with different designs and insertion techniques were evaluated (Fig 1). The NDNT large animal transfixation/casting pins2 have a central thread with a 6.3-mm-diameter core, an 8.0-mm-diameter thread, and a trocar tip. It is inserted after using a 6.2-mm-diameter drill bit followed by a centrally threaded tap. The SDST positive transfixation pins3 are a positive-profile centrally threaded transfixation pin with a core diameter of 6.3 mm and a thread diameter of 8.0 mm. It is designed with a drill point and 3 helical flutes for self-drilling and self-tapping.

Pairs of third metacarpal bones were harvested from adult horses euthanatized for reasons not associated with lameness. Bones were stripped of soft tissues and wrapped in saline (0.9% NaCl) solution-soaked towels and maintained at -20 C until testing. The day before implantation, bones were allowed to thaw to room temperature, and then they were placed in an incubator at 37 C for 8 hours prior to transfixation pin insertion. Bones were kept moist in saline solution-soaked towels until they were ready to use. Twenty-five pairs of bone-pin constructs were used for the experiments. Twelve pairs were used for pull-out testing, 10 pairs were submitted to cyclic loading before pull-out testing, and 3 pairs were used for thread evaluation by scanning electron microscopy.

**Pin insertion**—One metacarpal bone of each pair was implanted with a SDST transfixation pin and the contralateral metacarpal bone with a NDNT transfixation pin. Transfixation pins were inserted into the mid-diaphysis and randomly assigned to the right or left bone. Mid-diaphysis was determined to be 50% of the length of the bone from the proximal portion of the articular surface.

For NDNT transfixation pins, holes were predrilled with a 6.2-mm-diameter drill bit. Holes were tapped, and the transfixation pins were inserted using a low-speed transfixation pin driver. The SDST transfixation pins were inserted in 1 step using a low-speed transfixation pin driver. During insertion, the drill bit and tap for NDNT transfixation pins were each backed out and cleaned 2 to 3 times. The SDST transfixation pins were backed out and cleaned 5 to 6 times. A definite number of cleanings was not set, because it varies among bones, depending on bone width and cortical width. All transfixation pins were placed from cortex to cortex in a lateromedial direction.

The temperature of the tip of the drill bit, the cutting thread of the tap, and first thread of the transfixation pin were measured for NDNT transfixation pins. Temperature of
and photographed with a scanning electron microscope. Dehydrated through a graded series of ethanol solutions and not allowed to contact the trans-cortex where the temperatures were measured. A new drill bit and tap were used after every 10 bones.

After transfixation pin insertion, dorsopalmar and lateromedial radiographic views of each bone were taken to measure bone width and cortical width just proximal to the transfixation pins. Radiographic views were taken with double emulsion film and rare earth screens. Electrical current was set at 4 mA for both views, and the peak voltage for the dorsopalmar and lateromedial radiographic views were set at 63 and 66 kVp, respectively. Radiographs were evaluated for proper transfixation pin placement and to determine whether transfixation pin insertion created radiographically visible cortical fractures. Radiolucency around the transfixation pins was recorded, and the length of the lucent areas were measured and expressed as percentage of the cortical width of the cis-cortex.

Mechanical testing—For pull-out resistance, each bone-pin construct of 12 pairs of metacarpal bones were placed in an adjustable holding device designed for axial extraction of transfixation pins retrograde to placement in a material testing system. The metacarpal bones were held in 2 points, 1 point on each side of the transfixation pin 4 cm from the transfixation pin, and the transfixation pin was attached to the actuator. Tensile force at failure with a crosshead displacement rate of 0.3 mm/s was determined for each sample. Data collection was performed with custom designed software at 1,000 Hz.

For pull-out resistance after cyclic loading, 10 pairs of metacarpal bones were prepared as described. They were cyclic loaded 1,000 times from 0 to +2,225 N (500 lb) at a rate of 2 Hz. Bones were loaded from the proximal end while supported distally by the transfixation pins, simulating in vivo loading. Following cyclic loading, pull-out testing was performed as described.

Microstructural evaluation—Gross evaluation and scanning electron microscopic evaluation of the BPI were performed on 3 additional pairs of bone-pin constructs to determine cortical damage caused by transfixation pin insertion. One bone received 1 transfixation pin design, and the contralateral bone received the other. Transfixation pins were inserted as described. The cis- and the trans-cortex were identified, and the specimens were placed in 10% solution of formalin. Fixed specimens were cut through the long axis of the transfixation pin, transverse to the metacarpal bone, with a histologic bone band saw. The transected transfixation pins were lifted from their bed, and the specimens were examined and photographed. For electron microscopy, specimens were dehydrated through a graded series of ethanol solutions and then air and vacuum dried. They were mounted on a stub and gold-palladium sputter coated. Surfaces were evaluated and photographed with a scanning electron microscope. Micrographs of the cis- and trans-cortex were generated at a magnification ranging from 10 to 40X.

Calculations—The holding power (N/mm) was calculated by dividing the ultimate pull-out resistance by the total cortical width for holding power per cortical width (HPCW) and the total bone width for holding power per bone width (HPBW).

Statistical analysis—To compare the resistance to axial extraction between NDNT and SDST transfixation pins in each pair of metacarpal bones, a paired t-test was used for the noncyclic- and cyclic-loaded bones. A t-test for independent samples was used to compare holding power of each transfixation pin design before and after cyclic loading, the difference in temperature at each step of insertion, the radiolucent area in the cis-cortex of NDNT and SDST bone-pin constructs, and the thickness of the bones that did not fail with those that did. A P value of ≤ 0.05 was considered significant.

Results

Pin insertion—A total of 34 pairs of metacarpal bones were needed to obtain 25 usable pairs. Nine bones, all with SDST transfixation pins, fractured during transfixation pin insertion. Seven broke at the trans-cortex and 2 at the cis-cortex. Two broke while drilling the hole with the drill portion of the transfixation pin, and 7 broke when inserting the threaded portion of the transfixation pin into the drill hole. Eight bones developed saucer fractures of the trans-cortex, and 1 developed a trans-cortical longitudinal fissure originating from the transfixation pinhole extending proximally.

Temperature measurement—Temperatures of NDNT transfixation pins were consistently lower than SDST transfixation pins (Table 1). Temperature of NDNT taps and transfixation pins were significantly lower than the drill. Mean temperature of the drill point of SDST transfixation pins and the temperature of transfixation pins when the threaded portion exited the trans-cortex were not statistically different.

Radiographic evaluation—Radiographs confirmed that all the transfixation pins had been properly positioned through the mid-diaphysis of the metacarpal bones. Five of the 22 bones with NDNT transfixation pins had a thin radiolucent line around the transfixation pin in the cis-cortex involving 29.0 ± 7.9% (mean ± SD) of the width of the cis-cortex. All the bones with SDST transfixation pins had similar changes in the cis-cortex. The lucent area involved between 10 and 100% of the width of the cis-cortex with a mean of 60.3 ± 26.5%. The lucent area around the transfixation pin was significantly (P = < 0.001) greater for SDST than NDNT transfixation pins. None

Table 1—Mean (± SD) temperature measurements as each component of the external skeletal fixation device exited the trans-cortex of equine third metacarpal bones

<table>
<thead>
<tr>
<th>Variable</th>
<th>Drill bit</th>
<th>Tap</th>
<th>Pin thread</th>
<th>Drill point</th>
<th>Pin thread</th>
</tr>
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<tbody>
<tr>
<td>Temperature (°C)</td>
<td>60.08 ± 15.13&lt;sup&gt;a&lt;/sup&gt;</td>
<td>38.15 ± 6.18&lt;sup&gt;b&lt;/sup&gt;</td>
<td>42.53 ± 9.59&lt;sup&gt;c&lt;/sup&gt;</td>
<td>76.69 ± 15.92&lt;sup&gt;d&lt;/sup&gt;</td>
<td>72.73 ± 16.92&lt;sup&gt;e&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

<sup>a,b</sup>Means with different letters are significantly different from each other (P < 0.05).
NDNT = Nonself-drilling, nonself-tapping. SDST = Self-drilling, self-tapping.
of the metacarpal bones in which NDNT transfixation pins were inserted had radiographic evidence of periosteal cortical fracture. Eleven periosteal cortical fractures were detected in the 22 metacarpal bones with SDST transfixation pins. Eight were located in the trans-cortex and 3 in the cis-cortex.

**Resistance to axial extraction**—In the metacarpal bones with NDNT transfixation pins, 2 noncyclic-loaded bone-pin constructs and 2 cyclic-loaded bone-pin constructs did not fail before the material test system reached the load cell safety limit at 26.7 kN (6,000 lb). The SDST transfixation pins in contralateral metacarpal bone did fail but did not fracture. Pairs of bones where 1 of the bones did not fail were excluded from further analysis. These 4 pairs of bones that did not fail had a significantly greater (P < 0.001) total cortical width (mean ± SD, 25.99 ± 3.45 mm) than pairs that failed and fractured (19.75 ± 2.78 mm). Values for ultimate tensile strength, based on HPBW and HPCW, were significantly greater for NDNT than for the SDST transfixation pins (Table 2). For all variables, there was no difference between noncyclic- and cyclic-loaded metacarpal bones.

**Failure configuration**—The noncyclic- and cyclic-loaded bones failed in a similar fashion. Fracture configuration was the same for both, although the degree of comminution was less severe for bones with SDST transfixation pins. All fractures had 2 components—a comminuted fracture spiraling from the pinholes and a transverse fracture with various degree of comminution across both transfixation pinholes.

**Microstructural evaluation**—Gross and microscopic evaluation of the transected bones after pin removal revealed that metacarpal bones with SDST transfixation pins had severe thread damage, compared with NDNT transfixation pins where thread damage was minimal (Fig 2 and 3). Similar to the radiographic changes, much of the thread length of the cis-cortex was completely stripped by SDST transfixation pins, compared with NDNT transfixation pins where only the first threads of the cis-cortex were blunted. Debris was found in the trans-cortex in the flute track created by a SDST transfixation pin. No accumulation of debris was seen with NDNT transfixation pins. Gross evaluation did not indicate evidence of fractures with NDNT transfixation pins, but periosteal cortical fractures were seen in 2 trans-cortices and 1 cis-cortex with SDST transfixation pins (3 bones). Scanning electron microscopy revealed microfractures with both types of transfixation pins. With SDST transfixation pins, they were found in both cortices and associated with areas where debris was left in the flute path; there were 1 to 4 microfractures in the cis-cortex and 5 to 6 microfractures in the trans-cortex. Microfractures were only seen in the trans-cortex with NDNT transfixation pins with a lower number of 2 or 3.

**Table 2**—Mean (± SD) values of resistance to axial extraction of two designs of transfixation pins from equine third metacarpal bones

<table>
<thead>
<tr>
<th>Variable</th>
<th>NDNT transfixation pin</th>
<th>SDST transfixation pin</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Noncyclic loaded</td>
<td>Cyclic loaded</td>
</tr>
<tr>
<td>Ultimate tensile</td>
<td>20,713.14 (3,745.83)*</td>
<td>21,552.74 (3,381.61)*</td>
</tr>
<tr>
<td>strength (N)</td>
<td>15,861.02 (3,400.81)</td>
<td>133,310.19 (5,798.56)</td>
</tr>
<tr>
<td>HPBW (N/mm)</td>
<td>567.02 (80.02)*</td>
<td>608.75 (93.34)*</td>
</tr>
<tr>
<td></td>
<td>436.44 (99.84)</td>
<td>372.50 (159.94)</td>
</tr>
<tr>
<td>HPCW (N/mm)</td>
<td>1,028.66 (171.33)*</td>
<td>1,135.73 (145.37)*</td>
</tr>
<tr>
<td></td>
<td>744.67 (140.69)</td>
<td>697.37 (276.40)</td>
</tr>
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</table>

*P < 0.005 for paired comparison between NDNT and SDST transfixation pins.

N = Newtons. HPBW = Holding power per bone width. HPCW = Holding power per cortical width.
Discussion

Our results indicate that insertion of NDNT transfixation pins causes less macroscopic and microscopic damage to the bone than SDST transfixation pins. Less damage to the bone results in better resistance to axial extraction, reflecting a stronger initial BPI stability. Multiple factors can account for this. Radiolucency around the transfixation pin in the cis-cortex corresponded macroscopically and microscopically to stripping of the threads in the bone. This was substantially greater with SDST transfixation pins. Three explanations have been presented in the literature for the disparity of thread damage caused to the cis- and trans-cortex. It can be the result of microwobble in the cis-cortex during insertion caused by a greater length of transfixation pin passing through the cis-cortex, increasing the amount of thread disruption, or momentary halt in the linear advancement of the transfixation pin when it contacts the trans-cortex without a concomitant stop in its rotational momentum. In our study, the disruption of linear advancement of the tap/threaded portion of SDST transfixation pins could account for the more severe stripping of the thread in the cis-cortex of that bone-pin construct. Predrilling and tapping of the hole with NDNT transfixation pins would prevent the pin from stopping as it engaged the trans-cortex, thereby decreasing the stripping of the thread in the cis-cortex. Stripping of the thread in the cis-cortex decreases the contact between the bone and the transfixation pin, thereby compromising the BPI stability and resulting in decrease in holding power.

Long-term stability of the ESF is dependent on preventing osteonecrosis at the BPI. Our results indicate that the temperature of SDST transfixation pins during insertion was significantly higher than NDNT transfixation pins. Furthermore, it was consistently > 47°C, the temperature at which osteocyte death occurs. For NDNT transfixation pins the temperatures were > 47°C only during the first step of the insertion process. They were < 47°C for the remaining steps, reducing the possibility of bone necrosis. Predrilling a pilot hole before transfixation pin insertion will increase bone-pin stability by decreasing the temperature of the bone around the transfixation pin-hole and minimize thermal necrosis. Because the amount of time that the temperature remains > 47°C plays a role in the severity of the necrosis, one would assume that the damage caused by thermal necrosis would be more severe with SDST transfixation pins leading to a decreased BPI stability.

Our results are comparable to other studies in which threaded transfixation pins inserted after drilling a pilot hole caused less microstructural damage and thermal injury to the bone than transfixation pins that were inserted directly in the bone. Predrilling of the transfixation pin-hole also resulted in a better initial transfixation pin stability. In other studies in which transfixation pins inserted after predrilling were compared with SDST transfixation pins, a significant decrease in pull-out strength was seen with SDST transfixation pins.

Four of the NDNT bone-pin constructs did not fail during pull-out testing. Total cortical width of these bones was greater than those that did fail. Contralateral SDST transfixation pins did pull out but did not fracture. This is explained by a loss of stability caused by stripping of the thread in the cis-cortex and periostial cortical fracture, allowing the transfixation pin to slide out without enough resistance to fracture the bone. We hypothesize that the greater width of these bones can lead to more thread stripping of the cis-cortex. Therefore, performance of SDST transfixation pins is worse in bones with a greater diameter. However, wider bones with properly seated transfixation pins would provide greater transfixation stability at the BPI because of increased surface contact.

The difference in the transfixation pin design can account for the more severe damage caused by SDST transfixation pins and the decrease in the holding power. Microscopic evaluation revealed an increase in kerf left in the flute path and a substantial loss of threads in the cis-cortex. Both of these decrease bone-pin contact that ultimately reduces pull-out strength. Although both transfixation pins have the similar thread pitch and profile, the 3 helical flutes of SDST transfixation pins left debris in the threads and resulted in microfractures associated with the debris. Furthermore, the helical flutes decreased contact between the transfixation pin and the bone by 30%, as calculated from transfixation pin surface measurements.

Cyclic loading will propagate microfractures causing further implant loosening and decrease BPI stability. It is possible that the number of cycles used (1,000) and the load applied (2,225 N [500 lb]) were not enough to cause damage that would substantially alter the pull-out resistance of the cyclic-loaded transfixation pins. Furthermore, in vitro, the biological factors related to long-term loss of BPI stability did not come into effect. In vivo, bone reacts to cyclic loading, micromotion, and local bone strain at the bone-implant interface. However, initial stability at the BPI, as determined in our study, is important in determining how the BPI will respond in vivo. If the tissue strain is < 2%, undifferentiated cells will develop osteogenic activity, resulting in a more stable implant. If the strain is > 2%, chondrogenesis, fibrogenesis, and bone resorption will predominate and decrease the BPI stability. Stress protection, when the strain is less than an amount to stimulate bone formation, can develop, but is unlikely in this situation.

Failure configuration of both transfixation pins was the same except that the degree of comminution was less severe with SDST transfixation pins. Degree of comminution is related to the amount of energy needed to fracture a bone. These results support the fact that SDST transfixation pins were not as well anchored to the bone. This results in a decrease in resistance to extraction, thereby decreasing the pull-out force and creating fewer fragments.

This is an in vitro study using cadaver bones; therefore, we did not recreate all of the factors involved at the BPI, especially the osseous response to transfixation pin implantation and loading. This model only evaluated the acute effects of transfixation pin placement. However, the presence of stripped threads and
microfractures following insertion of SDST transfraction pins would be expected to lead to early transfraction pin loosening. Insertion of NDNF transfraction pins causes less damage to the bone and greater initial holding power, reflecting a better initial transfraction pin stability that should translate into a decreased incidence of early transfraction pin loosening.

References


