In vitro comparison of metaphyseal and diaphyseal placement of centrally threaded, positive-profile transfixation pins in the equine third metacarpal bone

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Objective—To evaluate in vitro holding power and associated microstructural and thermal damage from placement of positive-profile transfixation pins in the diaphysis and metaphysis of the equine third metacarpal bone.

Sample Population—Third metacarpal bones from 30 pairs of adult equine cadavers.

Procedure—Centrally threaded positive-profile transfixation pins were placed in the diaphysis of 1 metacarpal bone and the metaphysis of the opposite metacarpal bone of 15 pairs of bones. Tensile force at failure for axial extraction was measured with a materials testing system. An additional 15 pairs of metacarpal bones were tested similarly following cyclic loading. Microstructural damage was evaluated via scanning electron microscopy in another 6 pairs of metacarpal bones, 2 pairs in each of the following 3 groups: metacarpal bones with tapped holes and without transfixation pin placement, metacarpal bones following transfixation pin placement, and metacarpal bones following transfixation pin placement and cyclic loading. Temperature of the hardware was measured with a surface thermocouple in 12 additional metacarpal bones warmed to 38 C.

Results—The diaphysis provided significantly greater resistance to axial extraction than the metaphysis. There were no significant temperature differences between diaphyseal and metaphyseal placement. Microstructural damage was limited to occasional microfractures seen only in cortical bone of diaphyseal and metaphyseal locations. Microfractures originated during drilling and tapping but did not worsen following transfixation pin placement or cyclic loading.

Conclusions and Clinical Relevance—Centrally threaded, positive-profile transfixation pins have greater resistance to axial extraction in the diaphysis than in the metaphysis of equine third metacarpal bone in vitro. This information may be used to create more stable external skeletal fixation in horses with fractures. (Am J Vet Res 2000;61:1304–1308)

External skeletal fixation (ESF) is a valuable tool for managing selected fractures in horses. Use of ESF provides fracture stability and minimally disrupts the soft tissues and associated vascularity. With ESF, no implants are located at the fracture site to harbor microorganisms, and the fracture is not invaded, so infection is less likely to develop. Consequently, from the biological aspect of fracture healing, ESF is an important method of equine fracture repair. However, because of complications that can develop with ESF, its use has remained limited.

Premature loosening of the transfixation pins is the most common complication of ESF in horses. Transfixation pin loosening results from complex interactions between biological and mechanical factors. The small area of the bone-pin interface (BPI) is subject to weight-bearing forces, resulting in high bone stress. Loosening of the implant is initiated by microstructural and thermal damage that occurs when the transfixation pin is inserted into the bone. Cyclic loading of the implant subsequently propagates this microdamage. Strain between the implant and the bone during cyclic loading may increase osteoclastic activity and further contribute to transfixation pin loosening. In some instances, thermal and vascular injury during transfixation pin insertion can result in osteonecrosis and sequestration of a ring of bone around the transfixation pin. Premature loosening of the transfixation pins at the BPI commonly results in transfixation pin tract infection, signs of pain, and loss of fixation stability. The cycle of transfixation pin loosening and osteolysis at the BPI results in a progressive loss of cortical bone. As the cortical defect enlarges, there may be an increased potential for catastrophic failure through the BPI.

Threaded transfixation pins have an increased pull-out strength with minimal medial to lateral migration and a reduced occurrence of osteolysis and transfixation pin-tract infection than smooth pins. The combination of these effects results in greater patient comfort. Transfixation pins with threads cut into the shaft are weakened by the stress riser effect at the junction of the threaded and nenthreaded portion of the transfixation pin. This stress riser effect is reduced in positive thread profile transfixation pins that have an outer thread diameter greater than the shaft diameter.

The near cortex of the canine tibia has 25% less holding power than the far cortex as a result of insertion damage while the transfixation pin is engaging the far cortex. In the dense equine diaphysis, similar changes may develop, weakening the BPI. Placement of transfixation pins in the metaphysis may decrease the damage at the BPI. Another potential benefit of metaphyseal placement is that the drill holes create a proportionally smaller decrease in the cross-sectional area...
Materials and Methods

Pairs of equine 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. Metacarpal bones were slow thawed for 24 hours at 20°C before further preparation.

Mechanical testing—Dorsopalmar and lateromedial radiographic views were made with double emulsion film and rare earth screens to identify any abnormalities. Radiographs were used to measure the total bone width and total cortical width (sum of medial and lateral cortex) measured with a caliper at 50% (diaphysis) and 80% (distal portion of the metaphysis) of the length of the bone from the proximal portion of the articular surface. Fifteen pairs had transfixation pins randomly inserted through the diaphysis of 1 bone and the metaphysis of the contralateral metacarpal bone at the sites determined by radiographic measurements. Holes were predrilled with a 6.2-mm-diameter bit and tapped with the corresponding tap for a 6.35-mm-(0.25 in-) diameter, centrally located positive thread transfixation pin. Drilling was done with an air drill, and tapping and transfixation pin placement were done with a low-speed transfixation pin driver. Irrigation with saline solution at 20°C was maintained at a steady flow of 150 ml/min through an intervenous administration set during all steps of transfixation pin insertion. The drill and tap were intermittently reversed to clean the flutes. Irrigation was limited to the near (lateral) cortex. All transfixation pins were placed from cortex to cortex in a lateromedial direction. The bone-pin construct was placed in a specially designed jig for retrograde axial transfixation pin extraction in a materials testing system (Fig 1). Tensile force at failure with a crosshead displacement rate of 0.3 mm/s was determined from the load-displacement curve for each specimen. Data collection was performed with custom designed software at 1,000 Hz.

Another 15 pairs of metacarpal bones were prepared similarly and 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—Scanning electron microscopic evaluation of the BPI was performed on 6 pairs of bones, 2 pairs in each of 3 groups. In each pair, the BPI was placed in the diaphysis of 1 bone and the metaphysis of the contralateral bone. The 3 groups evaluated were metacarpal bones with tapped holes without transfixation pin placement (group-1 metacarpal bones), metacarpal bones with transfixation pins placed (group-2 metacarpal bones), and metacarpal bones with transfixation pins placed and cyclic loaded (group-3 metacarpal bones). Specimens were cut with a histologic bone band saw through the long axis of the hole for group-1 metacarpal bones and through long axis of the transfixation pin in the remaining group-2 and group-3 metacarpal bones. The transected transfixation pin was lifted from the bone, cis- and trans-cortices were identified, and the bone was fixed in a 10% solution of formalin. Specimens for electron microscopy were dehydrated through graded alcohol baths, then placed under vacuum. They were then mounted and coated with a gold-palladium sputter. Surfaces were evaluated and photographed with the scanning electron microscope. Micrographs of the cis- and trans-cortex were taken at magnification ranging from 10 to 40X. Microfractures were scored as follows: 1 = nondisplaced and ≤ 2 mm long, 2 = nondisplaced and > 2 mm long, and 3 = dis-
placed. Scores for each section were added, and a mean score for the 2 diaphyseal sections and the 2 metaphyseal sections in each of the 3 groups was determined.

Temperature determination—Twelve metacarpal bones that were harvested, stored, and thawed as described were placed in an incubator at 38°C for 8 hours. Transfixation pins were placed in the diaphysis and metaphysis of each metacarpal bone as described. Saline solution irrigation was limited to the near cortex and not allowed to contact the far cortex where temperatures were measured. Temperatures of the apex of the bit, cutting threads of the tap, and first thread of the transfixation pin were measured with a surface thermocouple when it exited the trans-cortex.

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 methods—For statistical comparison of pull-out resistance of the noncyclic- and cyclic-loaded metacarpal bones and temperature of the bit, tap, and transfixation pin between diaphyseal and metaphyseal placement, a paired t-test was used. A t-test for independent samples was used for comparison of cortical thickness of bones that did not fail to those that did. It was assumed that there were no geometric or structural differences between right and left metacarpal bones. Differences were considered significant at P ≤ 0.05.

Results

Mechanical testing—Results were obtained for 12 of 15 noncyclic-loaded pairs of metacarpal bones and for 11 of 15 pairs of cyclic-loaded metacarpal bones. The remaining 7 pairs were eliminated from the data set. One pair was eliminated because of a mechanical failure, and 6 pairs had at least 1 bone that did not fail before the predetermined maximal load of 26.7 kN (6,000 lb). Total cortical width of the 6 pairs that did not fail (mean ± SD, 24.3 ± 3.0 mm) was greater (P < 0.001) than those that did fail (20.4 ± 2.0 mm). The diaphysis provided significantly greater ultimate tensile strength than the metaphysis, but there was no significant difference of ultimate tensile strength between the noncyclic-loaded and the cyclic-loaded metacarpal bones (Table 1).

Failure configuration—The noncyclic-loaded and the cyclic-loaded metacarpal bones failed in similar fashion. Extraction following diaphyseal transfixation pin placement resulted in comminuted fractures spiraling from the transfixation pin holes; no shearing of bone threads occurred. Extraction following metaphyseal transfixation pin placement resulted in transverse fractures that broke out proximal and distal to the lateral transfixation pinhole in 20 bones. Three bones sheared the bone thread and slid out without fracturing the metacarpal bones.

Microstructural evaluation—Occasional microfractures were detected in the cortical bone following diaphyseal and metaphyseal transfixation pin placement (Fig 2 and 3). No microfractures were found in
the cancellous bone of the metaphysis. Microfractures emanated from the bottom of the thread tracks at the junction of the vertical and horizontal components in the cortical bone. Mean diaphyseal and metaphyseal scores were 9.5 and 5 for group-1 metacarpal bones, 5.5 and 0.5 for group-2 metacarpal bones, and 5 and 8.5 for group-3 metacarpal bones, respectively. No blunting or stripping of threads was found in any of the metacarpal bone groups.

Temperature determination—There was no significant temperature difference of the bit, tap, and transfixation pin between metaphyseal and diaphyseal placement. Group mean temperatures declined significantly from the bit to the tap and from the tap to the transfixation pin. Mean (± SD) temperatures of the bit, tap, and transfixation pin were 52.9 ± 7.8 C, 41.8 ± 4.3 C, and 33.2 ± 7.3 C for diaphyseal placement and 50.9 ± 9.8 C, 43.8 ± 5.3 C, and 33.2 ± 6.3 C for metaphyseal placement, respectively.

Discussion
The stability of the BPI is measured in vitro as holding power. Holding power of the transfixation pin is the peak axial tensile extraction force. Pull-out tests are influenced by multiple factors such as the thickness of the bone and the pull-out rate. Holding strength of screws increases with cortical bone thickness; similar to the transfixation pins tested in our study where failure did not occur in bones with the greatest total cortical width. The HPCW was greater for metaphyseal transfixation pin placement, because the contribution of the cancellous bone is not included in the calculation of HPCW. The loading rate used in our study (0.3 mm/s) is similar to the loading rate used in previous studies. In other species, increased strain rates increase strength and stiffness; however, this has not been investigated in the equine third metacarpal bone.

The mechanism of failure during axial extraction is thought to involve shearing of a cylinder of bone equal or slightly larger than the implant major diameter. Consequently, it is the major diameter of the threaded implant that is important in determining pull-out force. Other factors such as minor diameter of the transfixation pin and thread design and pitch have little effect. In our study, only 3 bones, all with metaphyseal implants, failed by shearing of the bone around the transfixation pin. The remainder of the bones failed by fracture, and minimal damage to the threads occurred. The major diameter of the transfixation pins in our study apparently exceeded the diameter where simple shearing of the bone occurs. The 6.35-mm (0.25-in-) diameter transfixation pin is being used clinically in adult large animals. Increasing the diameter of the transfixation pin increases the stiffness of the transfixation pin to the fourth power; however, it decreases the breaking strength of the bone. Mid-diaphyseal lateromedial drill holes in the equine metacarpal bone decreased torsional failure energy by 49 and 28% for 9.33-mm (0.375 in-) and 7.94-mm (0.31-in-) 3/16-in-diameter holes, respectively. There was a linear relationship between larger hole diameter and decreased failure energy.

The initial mechanical stability of the BPI is only 1 component of transfixation pin loosening. Development of transfixation pin loosening involves mechanical and biological events. Microstructural bone trauma caused by implant insertion serves as the initiating mechanical factor. Loading propagates microcracks. Biological alterations owing to vascular and thermal damage result in death of peri-implant bone.

We did not find a significant difference in pull-out resistance or microstructural damage between the noncyclic-loaded and cyclic-loaded specimens. Load or number of cycles may have been inadequate. Load was based on a ground reaction force of 60% of body weight at a walk. Clinically, 2 or 3 transfixation pins would be used, and the top transfixation pin would be subjected to a greater load than the lower transfixation pins; however, the exact load distribution has not been evaluated for a transfixation cast. For a 454-kg (1,000 lb) horse, a total load of 2,670 N (600 lb) would be expected. Our study loaded a single transfixation pin to 2,225 N (500 lb) that would account for 83% of the estimated load at a walk.

There were few microfractures in the noncyclic-loaded bones to propagate during cyclic loading. It is possible that some of the microfractures could originate during cutting of the specimens and transfixation pin removal, but unlikely. Microstructural damage was similar in the group that was only drilled and tapped to the groups that had transfixation pins placed and were cut in half and the transfixation pin removed. Further, the location of the microfractures was consistent. Data indicate that microfractures originated during tapping.

The surface thermocouple used in our study to measure temperature was easy to use and has been used in a previous investigation. The surface thermocouple provided rapid measurement of the temperature of the hardware that is in direct contact with the bone, but continuous measurement during insertion could not be made. Mean temperature for metaphyseal and diaphyseal placement exceeded 50 C, at which irreversible mechanical changes of bone may develop. Morphologic changes of bone may develop at temperatures as low as 47 C. Mean temperatures of the tap and transfixation pin were significantly lower than the drill. Because the temperature of the bone decreases rapidly at short distances from the transfixation pin-hole, the subsequent removal of bone with the tap may remove any bone damaged by thermal necrosis.

Temperatures in our study were lower than those recorded in another study. All of the equipment and environmental factors were the same; the only difference was the person placing the transfixation pins. This indicates that surgeon skills can play an important part in damage to the BPI. We did not elect to control this factor mechanically via instrumentation, because it cannot be controlled during surgery.

The conclusion of our study is that ultimate tensile strength and holding power based on bone width is higher for the diaphysis, and holding power based on cortical width is higher for the metaphysis, which is most likely caused by the contribution of the cancellous bone. Further studies are required to determine...
the optimal placement of transfixation pins for ESF on the horse.

1. Large animal transfixation/casting pin with central thread, Imex, Longview, Tex
2. ASIF small air drill, Synthes USA, Paoli, Pa.
3. Maxi driver, 3M, St Paul, Minn.
5. Exakt Macro Cutting Device, Exakt Technologies, Oklahoma City, Okla
7. Temperature surface probe Type K, Omega Engineering Inc, Stamford, Conn.

References