Insertional characteristics of three types of transfixation pin taps in third metacarpal bones from equine cadavers

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OBJECTIVE

To compare heat generation and mechanical bone damage achieved with 2 tapered and 1 cylindrical transfixation pin taps in third metacarpal bones from equine cadavers.

SAMPLE

18 pairs (36 specimens) of third metacarpal bones from euthanized horses with no known metacarpal disease.

PROCEDURES

In each bone, an investigator drilled 3 holes for placement of a 6.3-mm cylindrical transfixation pin, a 6.3-mm tapered pin using a prototype tapered tap, and a 6.3-mm tapered pin using a revised tapered tap. One bone of each pair was tapped by hand and the other with an electric drill. Temperatures of the drill bits, reamers, and taps were measured and used to compare heat generation among tap groups and tapping methods (hand vs power tapping). Macrodamage (all bone pairs) and microdamage (6 bone pairs) were assessed.

RESULTS

The revised tapered tap resulted in less heat generation and less total thread microdamage, compared with the prototype tapered and cylindrical taps. Power tapping created less bone damage but higher temperatures than did hand tapping for all bone groups.

CONCLUSIONS AND CLINICAL RELEVANCE

The revised tap design for tapered pin insertion was superior to the prototype tap design and yielded similar or less bone damage than achieved with cylindrical pin insertion in equine third metacarpal bone specimens. We recommend careful hand tapping for tapered pin insertion rather than power tapping, which generated greater heat. The revised tapered tap could be expected to perform better than a cylindrical pin tap in terms of thermal and mechanical microdamage and should be used for insertion of tapered transfixation pins. (*Am J Vet Res* 2020;81:172–179)

Transfixation pin casts may be used in horses for the treatment of comminuted phalangeal fractures, treatment of comminuted or open third metacarpal or metatarsal fractures, or facilitation of ankylosis in cases of septic arthritis in the distal limb region.[1–4] Placement of transcortical pins proximal to the fracture site and incorporation of the pins into a cast allow the horse to bear full weight on the limb with protection from bending forces and axial collapse. Reported success rates for such procedures range from 70% to 76%.[1,2] However, transfixation pin casts are associated with high rates of complications, with as many as 68% of procedures followed by pin loosening[1] and 14% to 20% followed by fracture at the pin site.[1,2] Other potential complications include pin tract bone sequestrum, pin breakage, and infection. Several studies[3,5,6] have examined the possibility of improving transfixation pin cast systems in horses by addressing pin-related complications. Nevertheless, the current practice of transfixation pin casting still involves the use of cylindrical, positive-profile pins.

The cause of the pin loosening is not fully understood but is believed to involve thermal and mechanical bone damage created during pin insertion that results in local bone resorption around the pin.[7] Adams et al[8] recently evaluated a tapered transfixation pin design for its ability to optimize transfixation pin insertion in horses by minimizing thermal and mechanical bone damage. This design also allows control over the torque applied at pin insertion. Tapered pins inserted into a tapered hole, tapped by use of a tapered tap, allow full contact with the bone only when the pin is near full insertion into the bone. Tapered pin insertion therefore results in less heat generation from friction, and osseointegrative coatings such as hydroxyapatite can be applied to the pins to facilitate pin integration.[8] Although tapered pins have been shown to generate less heat than standard cylindrical pins, use of tapered pins also results in greater bone damage, possibly as a result of the design of the tapered tap.[8]

The purpose of the study reported here was to follow up on the work of Adams et al,[8] with the goal of assessing a revised tapered tap design for use with tapered transfixation pin insertion in large animals. In addition, whereas previous studies[9,10] have evaluated the pull-out strength of screws following hand tapping versus power tapping (ie, by means of electric drill) and shown no difference, we are unaware of any studies in which the bone and thread damage created by power and hand tapping was evaluated. We therefore sought to compare heat generation and mechanical bone damage achieved with a revised tapered transfixation pin tap, a prototype tapered transfixation pin tap (the original tap used in the Adams et al[8] study), and a standard cylindrical transfixation pin tap during both hand and power tapping of third metacarpal bones from equine cadavers. We hypothesized that the revised tapered tap would yield less bone damage than would both the prototype tapered tap and the cylindrical tap. Additionally, we hypothesized that power tapping would generate more heat and bone damage than would hand tapping.

Materials and Methods

Bone specimens

Eighteen pairs of third metacarpal bones were harvested from 18 horses within 72 hours after euthanasia. These horses had been university owned or client owned; for client-owned horses, owner consent was obtained for collection of specimens after euthanasia. All horses had been euthanized for reasons unrelated to the study. Six horses had been euthanized because of lameness or fracture; however, in none were the metacarpal bones affected. Horses included 7 Quarter Horses, 3 American Paint Horses, 3 Thoroughbreds, and 1 Arabian, Standardbred, Hanoverian, Saddlebred, and mixed-breed horse. Age ranged from 8 months to 24 years (median, 10 years), and body weight ranged from 170 to 684 kg (mean, 486 kg).

Immediately following harvest, bones were wrapped in gauze soaked in saline (0.9% NaCl) or lactated Ringer solution, placed in a plastic bag, and frozen at –20°C. Prior to use in the study, bones were removed from the freezer and thawed at room temperature (approx 21°C) for 24 to 48 hours.

Treatment assignment

Bones were kept in pairs and arbitrarily assigned to an order of transfixation pin tap type to include 1 hole for each type (cylindrical tap, revised tapered tap, or prototype tapered tap; referred to as tap group) in the proximal, middle, or distal hole position, with the same position used for both bones in a pair. Hole positions (proximal, middle, or distal) were evenly distributed within each tap group and among the 3 tap groups. For each pair, 1 bone was used for hand tapping and the other for power tapping. Bones were kept moist with saline solution and saline solution–soaked gauze for the duration of the experiment.

Preparation for drilling

Before pilot holes were drilled, bones were stripped of soft tissues. Each bone was secured in a vise on a stand with the lateral aspect positioned as the topmost surface. A ruler was used to measure the length of the bone along its long axis (proximally to distally). The center of the bone was identified, and a permanent marker was used to mark the planned position of the middle hole. Marks were then created 20 mm proximal and distal to that mark to indicate where the center of the proximal and distal holes would be drilled.

Pin tract drilling

For each bone, the periosteum was cleared over each marked pin tract position, and then a pilot hole was drilled by hand with a 3.2-mm drill bit[a] and electric drill[b] centered over each of the 3 positions. Drilling was performed from a lateral to medial direction, with the lateral aspect as the topmost surface; however, in 1 pair, drilling was inadvertently performed from a medial to lateral direction owing to misidentification of the cortices of the bone. The flutes of the drill bit were cleaned as needed only during drilling of these pilot holes. A 5.0-mm drill bit[c] and electric drill were then used to enlarge the pilot hole drill tract.

Holes were subsequently drilled to accommodate 1 of 3 types of taps as assigned previously: a standard cylindrical tap for a 6.3-mm cylindrical pin, a prototype tapered tap design for a tapered 6.3-mm pin, or a revised tapered tap design for a tapered 6.3-mm pin. For cylindrical pin holes, a 6.2-mm drill bit[d] was used and the drill tract was tapped with a cylindrical tap.[e] For tapered pin holes, a 6.0-mm drill bit[f] was used initially and the hole was reamed[g] and tapped with the prototype tapered tap design[h] or the revised tapered tap design[i] **(Figure 1)**. Individual 6.0-mm and 6.2-mm drill bits were used a maximum of 6 times each before being replaced. Individual reamers were used a maximum of 12 times each before being replaced. All taps were used a maximum of 9 times each before being replaced.

Saline solution was applied at a rate of 150 mL/min to the cis cortex of each bone by means of a fluid pump and tube positioned at the interface of the bone and instruments during all drilling, reaming, and tapping procedures to help reduce heat generation. One investigator (LNM) performed all drilling procedures using a freehand technique. The drilling speed was approximately 900 rpm, with a maximum drill speed of 1,450 rpm. For consistency, once drilling had commenced with the 6.0-mm or 6.2-mm drill bits, it was continued across the entire bone width in 1 pass and flutes were not cleaned until drilling of the bone was complete. For each bone pair, one bone was tapped by hand with a large hand chuck and the

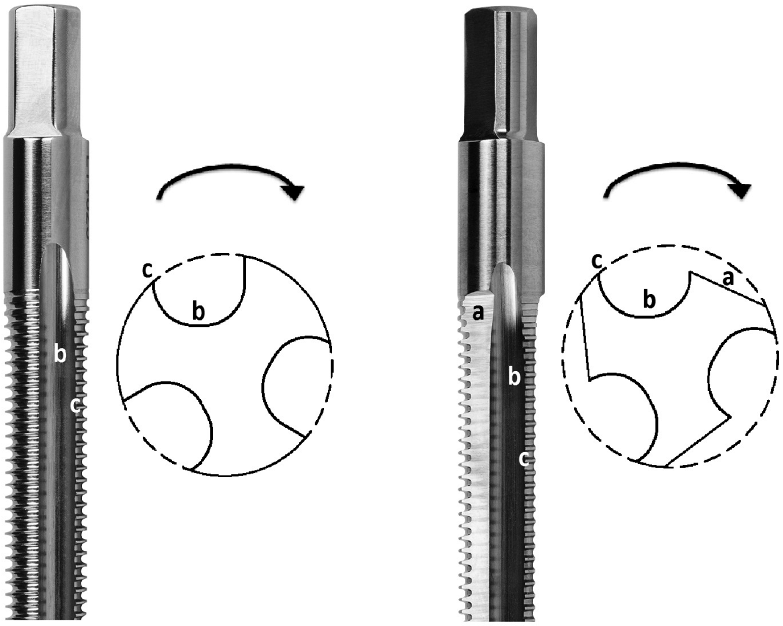

Figure 1—Photographs and illustrations of the cross-sectional profile of the prototype tapered tap design (left) and the revised tapered tap design (right) for use with tapered transfixation pins. Notice the shallower flutes and additional relief behind the cutting edge of the revised tapered tap versus the prototype tapered tap. The arrows show the direction of rotation of the taps during cutting. a = Relief behind the cutting edge. b = Flute. c = Cutting edge.

other was tapped with an electric drill. Hand tapping was performed with 2 complete forward turns and then a half turn backward to clear the flutes for both the cylindrical tap and tapered tap. Cylindrical and tapered holes alike were tapped until 3 threads of the tap were visible beyond the trans cortex of the bone. The same procedure was followed for power tapping with the electric drill; however, it was more difficult to ensure the 2 forward turns and the half turn backward were performed precisely.

Pin insertion

In 6 pairs of bones (pairs 13 to 18), pins were inserted and then removed after pin tract drilling and tapping. For this procedure, a stainless steel, positive-profile, cylindrical pin[j] with a core diameter of 6.3 mm and thread diameter of 8.0 mm was used for the cylindrical tap group. For both tapered tap groups, a stainless steel, positive-profile, tapered pin[k] was used with a leading core diameter of 6.3 mm and leading thread diameter of 7.5 mm, which enlarged at a taper of 5.7° to reach a maximum core diameter of 7.0 mm and maximum thread diameter of 8.2 mm at a thread length of 85 mm. Pin placement was performed manually by use of a torque wrench[l] that was set to alert when 4 N•m was reached for tapered pins. Cylindrical pins were inserted such that an even number of threads were present on both sides of the bone. Both pin types were inserted with consecutive complete turns. Maximum insertion torque for all pins was recorded prior to pin removal.

Temperature measurement

A contact temperature probe[m] was used to measure the temperature of the 6.0-mm and 6.2-mm drill bits, reamers, taps, and pins. All bones and hardware were maintained at room temperature during testing, although initial temperatures were not measured prior to use. The probe was applied to the hardware surface immediately after completion of each step at the trans cortex of the bone, and the peak temperature was recorded.

Pin tract analysis

After all pin tract drilling and tapping (pairs 1 to 12) and pin insertion and removal (pairs 13 to 18) procedures, each pin tract was flushed with saline solution and a 30° 4-mm arthroscope[n] was used to examine and video record the appearance of each drill tract. One investigator (LNM) analyzed the videos and recorded the number of visible chips per cortex, number of visible cracks per cortex, total number of threads per cortex, and total number of threads with visible damage (chips or cracks) per cortex. This investigator was blinded to the tap group to which each hole had been assigned. Chips were defined as an area of the thread that had a bone piece missing. The percentage of threads damaged per hole were calculated as the sum of observed thread damage at both the cis and trans cortex as a percentage of the total number of threads per hole.

For bones from pairs 7 through 12, micro-CT[o] was performed with the following scan parameters: voltage, 90 kV; current, 88 μA; voxel size, 120 μm^3; and total scan time, 14 minutes. All bone pairs were initially frozen at –20°C after video analysis. Five specimens were scanned via micro-CT while frozen. The remaining 7 specimens were thawed approximately 18 hours prior to scanning because motion artifacts were repeatedly observed for some frozen specimens. The pin tract appearance on micro-CT images was evaluated by 2 investigators (LNM and TBL), who used image analysis software[p] and 3-D bone filtering. These investigators were also blinded to the tap group to which each hole had been assigned. The number of chips per cortex, number of cracks per cortex, number of abnormal thread profiles (blunted or damaged appearance) per cortex **(Figure 2)**, total number of threads per cortex, total number of threads with damage per cortex, and length of any breakout damage **(Figure 3)** were recorded. Breakout damage was defined as damage to the trans cortex of the bone consisting of large pieces of bone to break off or delaminate. Total number of debris, defined as bone fragments within the threaded portion of the pin tract, was also recorded. The percentage of threads damaged per hole was calculated as the sum of observed damage at both the cis and trans cortices as a percentage of the total number of threads per hole.

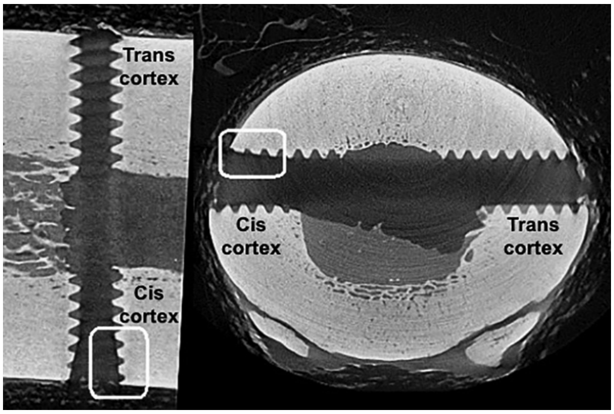

Figure 2—Representative dorsal (left) and transverse (right) plane micro-CT images showing an example of how blunted threads (highlighted by boxes) were identified in an equine third metacarpal bone specimen. This example shows a cylindrical tap tract, and blunted threads are visible at the cis cortex.

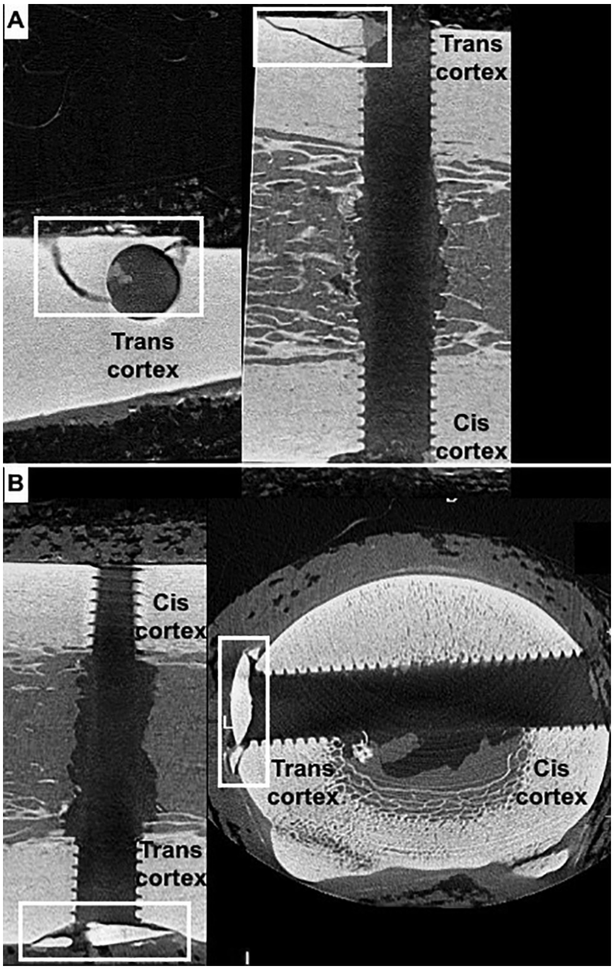

Figure 3—Representative sagittal (left) and dorsal (right) plane (A) and dorsal (left) and transverse (right) plane (B) micro-CT images showing an example of how breakout damage (highlighted by boxes) was identified and measured in an equine third metacarpal bone specimen. This example shows 2 different prototype tapered tap tracts, and breakout damage is visible at the trans cortex.

Statistical analysis

An a priori sample size calculation indicated that a minimum of 7 drill tracts would be needed per group to detect a significant difference in the percentage of threads damaged with a type I error rate (α) of 0.05 and power of 80%. For this calculation, estimates of the percentage of morphological thread damage were obtained from a previous comparison of tapered and cylindrical pins,[8] which showed that a mean of 22.8% of threads were damaged in the tapered pin group, compared with a mean of 1.8% in the cylindrical pin group, on histologic assessment of microdamage.

Maximum temperature data for drill bits, reamers, taps, and pins (dependent variables) were compared among various groups via mixed model analysis by use of a statistical software program.[q] Factors included as independent variables in the models were tap group, hole position (ie, proximal, middle, or distal), and tapping method (ie, hand or power tap; for tap temperature). Horse was included as a random variable. Residuals and raw temperature data were assessed for normality, and a natural logarithmic transformation of raw data was used if necessary to satisfy model assumptions and reduce data skewness. The Tukey method was used to perform multiple comparisons. Factors identified as nonsignificant (ie, $P \geq 0.05$) during the modeling process were excluded from the full model to arrive at a final reduced model for each variable examined.

Primary outcome (dependent) variables pertaining to bone damage included macroscopic damage (ie, total number of chips per tract, total number of cracks per tract, and total percentage of threads with macrodamage [combined total of chips and cracks]) and microdamage as detected via micro-CT (ie, total number of chips per tract, total number of cracks per tract, total debris seen in the drill tract, breakout damage thickness, and total percentage of threads with microdamage [combined total of chips, cracks, abnormal thread profiles, and threads affected by breakout damage]). Examination of raw data for these variables indicated that all but percentage of threads with microdamage were heavily skewed. Therefore, the same approach as used for temperature data was used to compare percentage of threads with microdamage among groups, and nonparametric ANOVA was used for the other bone damage variables. For all tests, values of $P < 0.05$ were considered significant.

Data regarding temperature and percentage of threads with microdamage are reported as mean ± SD. All other data are reported as median and range.

Results

Mean temperature of the 6.2-mm drill bit used in the cylindrical tap group (mean ± SD, 33.48 ± 5.55°C)

Table 1—Mean ± SD tap temperature and total percentage of macroscopic and microscopic thread damage in third metacarpal bones (n = 18 pairs) from equine cadavers in which an investigator drilled holes for placement of a 6.3-mm cylindrical transfixation pin, a 6.3-mm tapered pin using a prototype tapered tap, and a 6.3-mm tapered pin using a revised tapered tap via hand or power tapping (1 bone of each pair).

	Cylindrical tap			Prototype tapered tap			Revised tapered tap		
Variable	**Hand**	**Power**	**Hand and power combined**	**Hand**	**Power**	**Hand and power combined**	**Hand**	**Power**	**Hand and power combined**
Tap temperature (°C)	33.48 ± 1.73^{a}	46.84 ± 6.61^{b}	40.16 ± 8.23^{A}	35.01 ± 3.01^{a}	42.32 ± 6.38^{b}	38.66 ± 6.18^{A}	30.01 ± 3.24^{a}	36.77 ± 3.36^{b}	33.39 ± 4.73^{B}
Total percentage of macroscopic thread damage	2.55 ± 4.27	0.46 ± 1.96	1.51 ± 3.40	3.34 ± 5.82	1.79 ± 2.99	2.56 ± 4.56	0.00 ± 0.00	4.08 ± 7.30	2.04 ± 5.42
Total percentage of microscopic thread damage*	27.42 ± 8.27^{a}	18.81 ± 15.91^{b}	23.11 ± 12.90^{A}	30.74 ± 6.52^{a}	23.61 ± 9.90^{b}	27.18 ± 8.82^{A}	14.08 ± 12.43^{a}	9.76 ± 3.84^{b}	11.92 ± 9.05^{B}

*Only 6 pairs of assessed bones were examined via micro-CT for damage.

[a,b]Within a row, values with different lowercase letters differ significantly ($P < 0.05$) between hand and power tapping. [A,B]Within a row, values with different uppercase letters differ significantly ($P < 0.05$) between tap groups.

was significantly ($P < 0.001$) higher than that of the 6.0-mm drill bit used in the revised tapered (27.94 ± 3.31°C) and prototype tapered (27.73 ± 3.82°C) tap groups. Mean temperature of the reamer did not differ between the tapered tap groups (revised tap, 27.32 ± 1.56°C; prototype tap, 27.51 ± 1.27°C). The revised tapered tap generated significantly lower temperatures in both power- and hand-tapped bone specimens than did the cylindrical tap ($P = 0.002$) and prototype tapered tap ($P = 0.001$; **Table 1**). In all 3 tap groups combined, power tapping generated significantly ($P < 0.001$) higher temperatures (mean, 41.98 ± 6.99°C) than did hand tapping (32.83 ± 3.45°C). Power tapping had a significantly ($P = 0.004$) greater effect on tap temperature for the cylindrical tap than for the prototype and revised tapered taps. The mean increase in temperature due to power tapping (vs hand tapping) was 13.4°C for the cylindrical tap, 3.7°C for the revised tapered tap, and 7.3°C for the prototype tapered tap. No difference in mean temperature of the tapered (22.63 ± 1.75°C) or cylindrical (23.44 ± 2.80°C) pins was found following insertion.

Mean torque at insertion for the revised tapered pin (4.35 ± 0.38 N•m) and prototype tapered pin (4.51 ± 0.43 N•m) was similar. No difference was identified between power and hand tapping or among tap groups in the total number of chips or cracks identified on arthroscopic video analysis. There was also no difference among tap groups overall (ie, both hand and power tapping) in the total number of chips or cracks detected via video analysis. No difference in the total percentage of macroscopic thread damage detected via video analysis was identified among tap groups (Table 1).

The prototype tapered tap group had significantly more total microcracks detected via micro-CT (median, 0.83; range, 0 to 2) than did the revised tapered tap group (median, 0.17; range, 0 to 1; $P = 0.03$) and cylindrical tap group (median, 0.08; range, 0 to 1; $P = 0.01$). No difference was identified among tap groups in the number of total chips identified via micro-CT. The revised tapered tap resulted in a significantly lower percentage of total threads damaged as detected via micro-CT, compared with the prototype tapered tap ($P < 0.001$) and cylindrical tap ($P = 0.006$; Table 1). For all 3 tap groups combined, greater bone damage was observed with hand tapping (mean total percentage of microscopic thread damage, 24.08 ± 11.53%) than with power tapping (17.39 ± 11.94%; $P = 0.02$). No significant effect of hole position (proximal, middle, or distal) was identified in any analysis.

The median number of debris (ie, bone fragments within the threaded portion of the pin tract) as detected within the drill tracts via micro-CT was significantly less in the prototype tap group (1.17; range, 0 to 3) than in the revised tapered tap group (2.5; range, 1 to 4; $P = 0.008$) and cylindrical tap group (3.42; range, 2 to 8; $P = 0.001$). The median length of breakout damage detected via micro-CT at the trans cortex of the bone was significantly greater in the prototype tapered tap group (1.43 mm; range, 0 to 3.5 mm) than in the revised tapered tap group (0.23 mm; range, 0 to 0.9 mm; $P = 0.003$) and cylindrical tap group (0.12 mm; range, 0 to 0.7 mm; $P = 0.001$). No significant difference in the length of breakout damage was identified between the revised tapered tap and cylindrical tap groups. The prototype tapered tap group also had a greater proportion of bones with breakout damage (10/12) than did the revised tapered tap group (4/12) and cylindrical tap group (2/12).

Discussion

The results of the study reported here supported the clinical use of the revised tapered tap design with a tapered transfixation pin for transfixation pin casts in horses. The revised tapered tap resulted in less thread damage as detected via micro-CT than did both the prototype tapered tap and standard cylindrical tap. Additionally, the revised tapered tap generated lower temperatures overall than did the prototype tapered and cylindrical taps. The revised tapered tap evaluated in the study was modified to have shallower flutes and relief behind the cutting edge, compared with the prototype tapered tap previously evaluated by Adams et al.[8] Thread relief results in less contact of the tap thread surface area with the bone during the tapping process, yielding less frictional heat generation. Shallower flutes and a larger core result in a greater area moment of inertia, yielding a palpable decrease in flexibility of the revised tap relative to the previously reported prototype tap. The previously reported prototype tap, at times, would flex as well as make audible squeaking noises during tapping. In addition, less flexibility of the tap relative to that of the prototype version improved the stability of the cutting edge of the tap within the hole, resulting in a smoother cutting process and less thread damage. As previously reported,[8] the prototype tapered tap used in the present study did not advance smoothly through the hole and was noted to be more flexible during use than was the revised tapered tap. Higher temperatures were generated with power tapping versus hand tapping. Conversely, less bone damage was created with power tapping versus hand tapping overall.

Use of micro-CT in the present study allowed a detailed assessment of bone damage and detection of bone chips and microcracks as well as abnormal thread profiles and debris within the pin tract. Conversely, macrodamage assessment via arthroscopic video analysis, results for which were similar among the 3 tap groups, was less reliable in the evaluation of bone damage. The quality of scans was similar for both the frozen and thawed bone specimens; however, thawed specimens had fewer artifacts. Therefore, we recommend that specimens be thawed prior to scanning in future studies. Nevertheless, our experience suggested that scanning can be performed with bone specimens still wrapped in gauze and contained in a plastic bag.

Micro-CT has been used for various applications such as detection of calcified microcracks in equine third metacarpal bones,[11] bone density and trabecular structure in equine third metacarpal bones,[12] saw mark analysis in human bones,[13] assessment of bone implant contact,[14] assessment of bone microstructural changes from implants,[15] evaluation of experimentally induced implant infection in mice,[16] peri-implant bone damage,[17] and micro finite element modeling to predict stiffness for pullout testing of implants.[18] We found micro-CT to be an invaluable tool for morphological assessment of prepared pin tracts. Compared with 2-D histologic approaches, micro-CT allowed a more complete assessment of bone damage given that the entire volume of the pin tract and corresponding threads could be evaluated in 3 orthogonal planes without disruption of the tract. More damage was found with micro-CT in our study considering the percentage of thread damage (mean for hand and power tapping combined, 27.18% for the prototype tapered tap and 23.11% for the cylindrical tap) than was found in the previous study[8] via histologic examination of bones (22.8% for tapered pins and 1.8% for cylindrical pins). This difference was likely due to the greater visibility of threads via micro-CT versus histologic examination.

Stereomicroscopy may be more sensitive than arthroscopic video analysis for the evaluation of macroscopic pin tract damage. Surface staining may also have improved contrast identification and assessment of damage via arthroscopic video analysis. Although micro-CT was used to evaluate only 6 pairs of bones for damage in the present study, these 6 pairs of bones provided 12 pin tracts for each group for comparison and represented an adequate sample size as indicated by our initial sample size calculations.

Despite consistent flushing of the holes with saline solution following tapping in the present study, more debris within the pin tract was seen with the revised tapered and cylindrical taps versus the prototype tapered tap. Use of the revised tapered tap may result in residual debris owing to the shallower flute depth and added thread relief, which might allow debris to move back into the tapped hole during tap removal along the tapered pin tract. The cylindrical tap, which has flutes only at the tip, may be more prone to dropping debris because all bone tapping action and the resulting bone debris are generated along the lead threads of the tap, locally overfilling the flutes, which are smaller in the cylindrical tap. Additional studies would be needed to determine the exact cause for debris within the drill tract and its clinical importance. Although the drill tracts were flushed at the conclusion of tapping prior to arthroscopic video and micro-CT analysis, additional and more aggressive flushing of the drill tracts might help to reduce the amount of debris within the tract in clinical situations.

Lower temperatures were recorded when drilling was performed with the 6.0-mm drill bit for both tapered tap groups in the present study than when it was performed with the 6.2-mm drill bit for the cylindrical tap group, which was consistent with previously reported findings.[8] The approximately 6°C increase in mean drill temperature from the 6.0-mm to the 6.2-mm drill bit was likely due to a combination of both a larger web thickness as well as a difference in point, cutting edge, or helical geometry. This temperature difference between drill bits was less than previously reported[8]; however, the pilot hole used in the present study was larger (5.0 mm vs 3.2 mm), resulting in less bone removal during the drilling step. The revised tapered tap generated lower temperatures than did both the cylindrical and prototype tapered taps. The revised tapered tap had relief behind the cutting edge, reducing surface contact with the bone and resulting in less friction. In addition, with a tapered tap, thread cutting occurs over the entire length of the tap rather than over the course of the first few threads, as in the standard cylindrical tap.

Power tapping with an electric drill generated significantly higher temperatures than did hand tapping for all tap groups in the study reported here. This was most likely owing to the higher speed and briefer overall time of power tapping. Heating of bone to 47°C for 1 minute can create irreversible bone damage[15–19]; however, thermal osteonecrosis is a complex and dynamic process and no threshold for temperatures has been established for equine bones.[20] Despite all taps starting at room temperature, the mean temperature for the cylindrical tap group was near 47°C for power tapping, with individual temperatures exceeding 47°C in 10 of the 18 bone specimens. Temperatures for the tapered taps did not reach 47°C, except with power tapping and the prototype tapered tap in 2 bone specimens. No tap temperatures reached 47°C in any group with hand tapping. These findings highlighted the large increase in instrument temperatures generated during implant preparation, with a mean increase observed for power tapping of approximately 26°C from room temperature (21°C) for the cylindrical tap group and approximately 15°C from room temperature for the revised tapered tap group. A limitation of such temperature measurements was the use of only the contact temperature probe. Nevertheless, in a previous study[8] in our laboratory, a strong correlation in measured temperatures was observed among bone-implanted thermocouples, a contact temperature probe, and thermography. Accordingly, although absolute values of temperature measurements may differ with the equipment used, we believe our findings were valid.

Power tapping in the present study also resulted in less bone damage in all tap groups as detected via micro-CT. This was an unexpected finding, and the cause of greater bone damage with hand tapping remains unclear. Hand tapping may have generated more damage because of the greater wobbling of the tap than achieved with power tapping. Overall, the increase in bone damage achieved with hand tapping (vs power tapping) in the revised tapered tap group was relatively small. When considering both thermal and mechanical effects together, in light of the potential for thermal bone damage from power tapping and the small increase in mechanical bone damage with hand tapping for the revised tapered tap, we recommend careful hand tapping over power tapping to help minimize overall insertional damage of tapered transfixation pins.

We believe that the revised tap design for tapered pin insertion as evaluated in the present study is an improvement over the prototype design; its use generated less bone damage than taps for cylindrical pin insertion as indicated by microdamage assessment. Our findings supported use of the revised tapered tap and tapered transfixation pins for transfixation pin casts in horses. Although power tapping created less bone damage than did hand tapping, we do not believe the advantage would be clinically relevant enough to offset the higher temperatures achieved when power tapping was used for the revised tapered tap design.

Acknowledgments

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Dr. Griffin is the owner of IMEX Veterinary Inc. The authors declare that there were no other conflicts of interest.

Footnotes

a. 3.2 X 130-mm Jacobs chuck drill bit, Synthes, Monument, Colo.
b. 14.4-V, 0.5-inch (13-mm) cordless compact drill and driver kit, Dewalt, Baltimore, Md.
c. 5.0 X 92-mm CTD metric magnum super premium drill bit, Consolidated Toledo Drill & Tool, Saint Paul, Minn.
d. 6.2 X 175-mm StickTite drill bit, PN 32062, IMEX Veterinary Inc, Longview, Tex.
e. Cylindrical tap, PN 2114T, IMEX Veterinary Inc, Longview, Tex.
f. 6.0 X 175-mm drill bit, PN 78565900, MSC Industrial Supply, Melville, NY.
g. Tapered reamer, PN PPT001-1-2, IMEX Veterinary Inc, Longview, Tex.
h. Tapered tap prototype, PN PPT001-2V3 lot 14825, IMEX Veterinary Inc, Longview, Tex.
i. Tapered tap revision, PN PPT001-2V3 lot 18432, IMEX Veterinary Inc, Longview, Tex.
j. Cylindrical Duraface full-pin for large animals, PN 22140, IMEX Veterinary Inc, Longview, Tex.
k. Large animal transfixation pin, 85-mm central thread, PN PPT001-5, IMEX Veterinary Inc, Longview, Tex.
l. Electrotork electronic torque wrench, Snap-On Inc, Kenosha, Wis.
m. Temperature surface probe type K, Omega Engineering Inc, Stamford, Conn.
n. 4-mm 30° arthroscope, Stryker, Kalamazoo, Mich.
o. Quantum GX microCT, PN CLS140083, PerkinElmer, Waltham, Mass.
p. PerkinElmer simple viewer, version 5.5.0.14, PerkinElmer, Waltham, Mass.
q. SAS, version 9.4, SAS Institute Inc, Cary, NC.

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