Effect of diameter of the drill hole on torque of screw insertion and pushout strength for headless tapered compression screws in simulated fractures of the lateral condyle of the equine third metacarpal bone

Ryan S. Carpenter, DVM; Larry D. Galuppo, DVM; Susan M. Stover DVM,PhD

Objective—To compare variables for screw insertion, pushout strength, and failure modes for a headless tapered compression screw inserted in standard and oversize holes in a simulated lateral condylar fracture model.

Sample Population—6 pairs of third metacarpal bones from horse cadavers.

Procedure—Simulated lateral condylar fractures were created, reduced, and stabilized with a headless tapered compression screw by use of a standard or oversize hole. Torque, work, and time for drilling, tapping, and screw insertion were measured during site preparation and screw implantation. Axial load and displacement were measured during screw pushout. Effects of drill hole size on variables for screw insertion and screw pushout were assessed by use of Wilcoxon tests.

Results—Drill time was 59% greater for oversize holes than for standard holes. Variables for tapping (mean maximum torque, total work, positive work, and time) were 42%, 70%, 73%, and 58% less, respectively, for oversize holes, compared with standard holes. Variables for screw pushout testing (mean yield load, failure load, failure displacement, and failure energy) were 40%, 40%, 47%, and 71% less, respectively, for oversize holes, compared with standard holes. Screws could not be completely inserted in 1 standard and 2 oversize holes.

Conclusions and Clinical Relevance—Enlarging the diameter of the drill hole facilitated tapping but decreased overall holding strength of screws. Therefore, holes with a standard diameter are recommended for implantation of variable pitch screws whenever possible. During implantation, care should be taken to ensure that screw threads follow tapped bone threads. (*Am J Vet Res* 2006;67:895–900)

Parasagital, distal articular fractures of the lateral condyle of the MC3 are common among Thoroughbreds involved in racing.[1-3] Use of lag screws to reduce such fractures results in return to racing for approximately two thirds of horses.[4] Impingement on the collateral ligament by a distally located screw may cause persistent pain or necessitate a second surgery for screw removal, and it increases risk for surgical complications, healing time, and treatment costs.[5] However, screw removal remains controversial.[6] Exact realignment of the articular surface and stable reduction are critical for prevention of osteoarthritis and delayed fracture healing.[7] Consequently, repair of lateral condylar fractures could be enhanced by avoiding interference between surgical implants and soft tissues and improving interfragmentary stability.

ABBREVIATIONS

MC3	Third metacarpal bone

A headless, tapered, fully threaded, variable-pitch, self-tapping screw[a] (ie, headless tapered compression screw) originally designed for orthopedic disorders in humans[8] has been used in horses. The headless design allows the screws to be completely implanted beneath the bone surface, which avoids interference with overlying soft tissues. The shaft is fully threaded with the distance between threads becoming narrower from apex to base. The fully threaded, tapered, variable-pitch design creates a large bone-screw interface for threads to engage bone on both sides of the fracture site and generate bone compression along the entire length of the screw shaft as the screw is tightened.[8] These features are desirable for stabilization of lateral condylar fractures in the MC3s of horses, a location at which screws are positioned through the lateral collateral ligament of the metacarpophalangeal joint, and interfragmentary compression and prolonged stability are essential for optimal fracture healing.

Headless tapered compression screws have been used clinically to stabilize nondisplaced lateral condylar fractures of the metacarpus in racing Thoroughbreds.[9]

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From the JD Wheat Veterinary Orthopedic Research Laboratory (Carpenter, Stover) and the Department of Surgical and Radiological Sciences (Galuppo), School of Veterinary Medicine, University of California, Davis, CA 95616. Dr. Carpenter's present address is Equine Medical and Surgical Group, PO Box 661956, Arcadia, CA 91066.

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Address correspondence to Dr. Galuppo.

Although early results have been positive, it can be difficult to insert the headless screws in bones of horses.[9] The screws may become locked in the bone before they are fully inserted, which results in impingement on the collateral ligament as a result of screw protrusion and suboptimal interfragmentary compression and stabilization as a result of an incomplete screw-bone interface. One potential solution for this problem is to drill a hole with a larger diameter for screw placement. The resulting smaller screw thread–bone contact area should decrease insertion torque and likelihood of the screw becoming locked in the bone before complete insertion. However, smaller contact area may decrease screw-bone holding strength and compromise interfragmentary stabilization.

In dense bone tissue, holding strength of an implant may not be affected by a smaller screw thread–bone contact area. If bony tissue between adjacent threads can support the screw threads, then screw pushout strength would likely be proportional to the outer diameter of the screw thread because failure (screw pushout) results from shear forces along the cylindrical interface (which is a conical interface in the case of the tapered screw) between the outer margin of the screw threads and surrounding bone tissue. Because the equine metacarpal condyle is formed of dense bone tissue, it was hypothesized that the hole for screw insertion could be enlarged to facilitate complete insertion of screws without affecting screw-bone holding strength. The objectives of the study reported here were to evaluate variables for screw insertion and mechanical properties for screw pushout for the tapered compression screw inserted in a standard and an oversize hole. This information, obtained in a controlled environment, should facilitate clinicians and researchers in making appropriate recommendations regarding optimal screw insertion to reduce fractures.

Materials and Methods

Sample population—Bilateral MC3s with no gross evidence of osteoarthritis of the metacarpophalangeal (fetlock) joint were collected from 6 cadavers of racing Thoroughbreds (2 females, 4 geldings; mean age ± SD, 3.5 ± 1.8 years; range 2 to 7 years). All horses were euthanized for reasons unrelated to osteoarthritis of the fetlock joint.

Specimen preparation—Specimens were obtained immediately after horses were euthanized. Specimens were wrapped in towels soaked with physiologic saline (0.9% NaCl) solution, placed in plastic bags, and stored at –25°C until testing. Bones were thawed in a refrigerator (5°C) for 24 hours and then at room temperature (20°C) in physiologic saline solution for 24 hours before additional preparation and mechanical testing.

One metacarpus from each pair was randomly assigned to the standard drill hole group, whereas the contralateral bone was assigned to the oversize hole group. All bones were continuously irrigated with physiologic saline solution during sawing, drilling, tapping, and screw insertion procedures. A bone saw and guide were used to create a 4-cm-long parasagittal osteotomy in the lateral condyle at a location 1 cm axial to the outer cortical surface. The distal two thirds of the MC3 was embedded in polymethylmethacrylate[b] in a bone jig with orthogonal surfaces to ensure standardized positioning (**Figure 1**). A portion (6 cm) of the lateral and medial aspects of the distal portion of MC3 was exposed. The simulated lateral condylar fracture was reduced by use of 2 pairs of Association for the Study of Internal Fixation bone-reduction forceps (1 pair was positioned dorsal to, and the second pair was positioned palmar to, the lateral epicondylar fossa to avoid interfering with drilling and screw insertion).

Hole preparation and screw insertion—Each bone specimen was mounted on a drill press with the site of screw insertion centered on a biaxial load cell. Measurements of variables for drilling, tapping, and screw insertion were recorded at 100 Hz.[9,10] To standardize drill speed and preparation of holes for screw insertion, a drill press was centered over the epicondylar fossa of the lateral condyle and aligned perpendicular to the osteotomy and parallel to the articular surface. A 14.5-cm-long cylindrical drill bit[c] was used to drill a pilot hole (3.2 mm in diameter) through the fracture fragment and parent epiphyseal bone in a lateral to medial direction (completely exiting the medial condyle). Depending on the group to which a specimen was assigned, a standard or oversize (0.44 mm larger in diameter at the base and 0.41 mm larger in diameter at the apex of the drill bit) tapered drill bit was used to create a 50-mm-long screw hole in the lateral epicondylar fossa (**Figure 2**). A 45-mm-long tapered bone tap was manually inserted to create bone threads for screw insertion. Each hole was tapped to a distance of 46 mm (1 mm beneath the cortical surface). After tapping, a headless tapered compression screw[a] was manually inserted (**Figure 3**). Data for torque and amount of time during drilling, tapping, and screw insertion were converted by an analogue-digital conversion program[d] and stored in data files.

Mechanical pushout testing—After screw insertion, the distal 1 cm of the fracture fragment was removed to allow

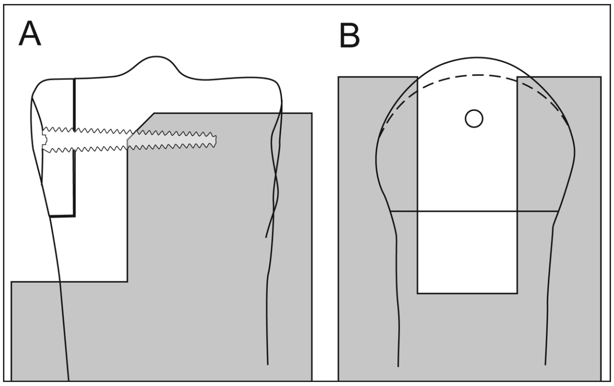

Figure 1—Diagrams of dorsal (A) and medial (B) views of the distal end of an MC3 (white area) embedded within polymethylmethacrylate (gray area) in the bone jig. Notice the saw cuts that simulate a fracture (4-cm-long segment of bone) of the lateral condyle (dotted line on medial view) with the headless tapered compression screw inserted.

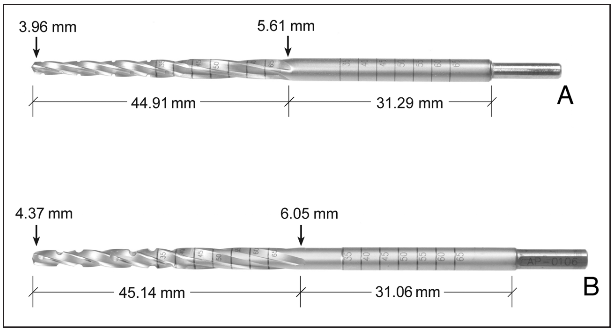

Figure 2—Diagrams of the specific dimensions of the standard (A) and oversize (B) tapered drill bits. Notice the marks at increments of 5 mm that enhance accuracy of drilling.

support of the parent bone during pushout testing. The bone jig was rotated 180° to maintain screw alignment when we accessed the screw apex. The medial aspect of the 3.2-mm pilot hole was enlarged to the distal end of the headless tapered compression screw by use of a 4.5-mm-diameter, 14.5-cm-long cylindrical drill bit.[e] A 4.5-mm-diameter pushout device was inserted to the level of the screw apex. Each MC3 construct was then aligned in a materials' testing machine[f] equipped with a load cell for pushout tests (**Figure 4**). The headless tapered compression screw was pushed from the parent bone at a constant displacement rate of 1 mm/min; load, displacement, and time were measured at 100 Hz. Mechanical pushout data were converted by use of an analogue-digital conversion program[d] and stored in data files.

Measurement of failure mode—After mechanical testing, each MC3 construct was removed from the bone jig and polymethylmethacrylate. A dorsopalmar radiograph (75 kV, 0.0062 seconds, and 500 mA)[g] was taken of each construct on a digital radiograph cassette.[h] Radiographs were examined to determine failure mode for each screw pushout test, which was categorized as bone failure, screw failure, or failure of the bone-screw interface with or without screw deformation.

Data calculations—Mean ± SD values were calculated for standard and oversize hole groups for all variables of drilling, tapping, and screw insertion (mean maximum torque, positive work, negative work, total work, and total time). Mechanical properties for pushout testing (stiffness, yield displacements, yield loads, yield energies, failure displacements, failure loads, and failure energies) were derived from load-deformation curves generated from mechanical pushout data (**Figure 5**). Yield was defined as the point at which the curve visually deviated from the initial linear region. Stiffness was defined as the slope of the linear region. Failure was defined as the point of maximum load. Loads and displacements for yield and failure were determined by the respective values for the yield and failure points. Energies for yield and failure were derived from the area under the curve corresponding to the yield and failure points, respectively.

Statistical analysis—Effects of hole size (standard vs oversize) on screw insertion and mechanical properties during pushout testing were evaluated by use of the Wilcoxon signed rank test for nonparametric paired data. Effects of deformation of the screw tip (deformed or not deformed) on mechanical properties during pushout testing were also evaluated by use of the Wilcoxon test. Significance was designated at values of $P < 0.05$. Relationships between variables for site preparation and screw insertion and site preparation and screw pushout were assessed by use of Spearman correlations. Adjustments (eg, Bonferroni) were not made for multiple tests.

Results

In 3 bone specimens, the headless tapered compression screws became locked in the bone before they were completely inserted within the metacarpal condyle. The base of 1 screw in a standard-size hole protruded 2 mm above the lateral epicondylar fossa. The base of the 2 incompletely inserted screws in oversize holes protruded 4 and 6 mm, respectively, above the lateral epicondylar fossa.

We did not detect significant differences for screw implantation variables between standard and oversize holes for the drilling variables maximum torque, total work, positive work, and negative work (**Table 1**). However, mean time to drill oversize holes was significantly ($P = 0.031$) longer (41.3 seconds [59%]), compared with the amount of time needed to drill standard holes. Mean maximum torque for tapping was significantly ($P = 0.031$) less (1.3 N•m [42%]) for oversize holes, compared with maximum torque for standard holes. Mean total work and positive work to tap oversize holes were significantly ($P = 0.031$) less (71.2 N•m•s [70%] and 27.5 N•m•s [27%], respectively), compared with values for standard holes. Mean time to tap oversize holes was significantly ($P = 0.031$) less

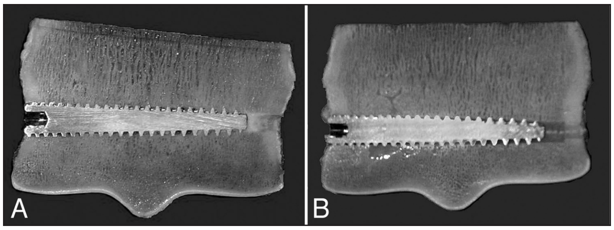

Figure 3—Photographs of the distal end of the MC3 with a headless tapered compression screw inserted into a standard (A) and oversize (B) hole. Each MC3 was sectioned along a transverse plane centered over the middle of the screw.

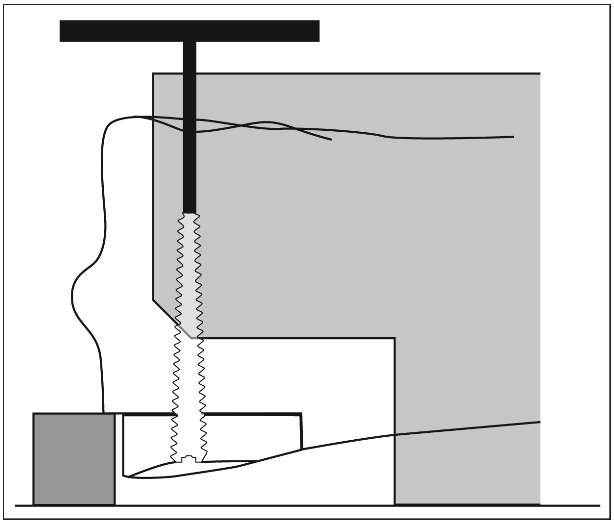

Figure 4—Diagram of a dorsal view of the distal end of an MC3 (white area) embedded within polymethylmethacrylate (gray area) in the bone jig mounted on a materials' testing machine with the pushout rod (black T-shaped rod) inserted to the level of the apex of a headless tapered compression screw. The distal 1 cm of the fracture fragment was removed to allow additional stabilization of the parent bone during mechanical pushout testing.

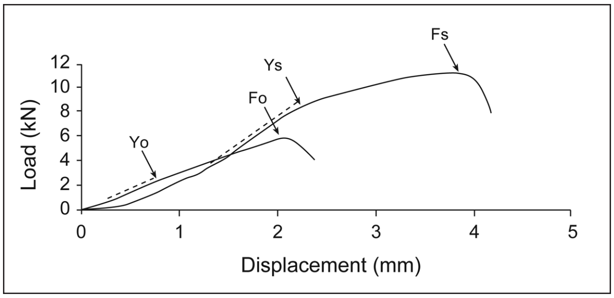

Figure 5—Representative load-deformation curves obtained by use of a headless tapered compression screw inserted in a standard or an oversize hole. Notice the yield points (Yo and Ys) for the oversize and standard holes, respectively. The ultimate failure points (Fo and Fs) are also indicated for the oversize and standard holes, respectively. Slope of the elastic portion of each curve (dashed lines) represents the stiffness of the screw-bone construct.

Table 1—Mean ± SD values for insertion variables obtained by insertion of a headless tapered compression screw in a standard or oversize hole in a simulated lateral condylar fracture of the equine MC3.

Insertion variable	Hole	Maximum torque (N•m)	Total work (N•m•s)	Positive work (N•m•s)	Negative work (N•m•s)	Time (s)
Drill	Standard	1.5 ± 0.6	46.6 ± 26.0	7.3 ± 5.1	39.3 ± 26.8	69.9 ± 15.7*
	Oversize	2.0 ± 1.0	61.4 ± 14.1	18.7 ± 19.0	42.6 ± 20.4	111.2 ± 9.0
Tap	Standard	3.1 ± 0.5*	1 01.9 ± 53.0*	37.5 ± 27.2*	64.5 ± 51.3	151.0 ± 62.9*
	Oversize	1.8 ± 0.7	30.7 ± 22.0	10.0 ± 8.6	20.7 ± 22.7	62.7 ± 22.6
Screw	Standard	4.4 ± 1.5	104.9 ± 86.9	25.9 ± 17.3	79.0 ± 73.0	158.3 ± 142.6
	Oversize	3.8 ± 1.0	148.8 ± 70.9	60.4 ± 68.0	88.3 ± 74.2	214.6 ± 140.6

*Within a column within a variable, value differs significantly ($P < 0.05$) from the value for the oversize hole.

Table 2—Mean ± SD values for pushout variables obtained by use of a headless tapered compression screw inserted in a standard or oversize hole in a simulated lateral condylar fracture of the equine MC3.

	Yield				Failure		
Hole	Load (kN)	Displacement (mm)	Energy (kN•mm)	Stiffness (kN/mm)	Load (kN)	Displacement (mm)	Energy (kN•/mm)
Standard	9.1 ± 1.2*	1.3 ± 0.5	8.1 ± 3.1	4.9 ± 0.7	12.1 ± 2.6*	3.2 ± 1.1*	29.3 ± 16.3*
Oversize	5.7 ± 1.5	1.0 ± 0.3	3.6 ± 1.4	4.6 ± 2.0	7.3 ± 2.0	1.7 ± 0.3	8.4 ± 4.6

See Table 1 for key.

Table 3—Mean ± SD values for pushout variables obtained for headless tapered compression screws with or without a deformed tip.

	Yield				Failure		
Hole	Load (kN)	Displacement (mm)	Energy (kN•mm)	Stiffness (kN/mm)	Load (kN)	Displacement (mm)	Energy (kN•/mm)
Not deformed	6.7 ± 2.1*	1.1 ± 0.4	4.7 ± 2.8*	4.9 ± 1.7	8.3 ± 2.5*	1.9 ± 0.6*	11.7 ± 8.2*
Deformed	9.3 ± 0.9	1.4 ± 0.2	9.4 ± 1.6	4.3 ± 0.1	14.0 ± 1.1	4.0 ± 0.6	40.4 ± 12.2

*Within a column, value differs significantly ($P < 0.05$) from the value for the screws with a deformed tip.

(88.3 seconds [58%]), compared with the time needed to tap standard holes. Mean negative work to tap standard holes did not differ significantly from mean negative work needed to tap oversize holes. Variables for screw insertion did not differ significantly between standard and oversize holes.

For screw pushout, mean yield load and mean failure load were significantly ($P = 0.031$) less (3.4 kN [37%] and 4.8 kN [40%], respectively) for oversize holes, compared with values for standard holes (**Table 2**). Mean failure displacement was significantly ($P = 0.031$) less (1.5 mm [47%]) for oversize holes, compared with failure displacement for standard holes. Mean failure energy was significantly ($P = 0.031$) less (20.9 kN•mm [71%]) for oversize holes, compared with failure energy for standard holes. Mean yield displacement, mean yield energy, and stiffness did not differ significantly between oversize and standard hole groups.

The failure of all constructs was attributable to bone failure at the bone-screw interface in the parent bone fragment. However, the pushout rod deformed the apex of 3 screws (all in standard holes) before bone failure. For screw pushout, mean yield and mean failure loads were significantly ($P = 0.002$ and $P = 0.008$, respectively) greater (2.7 kN [29%] and 5.7 kN [41%], respectively) for screws with deformed tips, compared with values for screws without deformed tips (**Table 3**). Mean yield and mean failure energies were significantly ($P = 0.003$ and $P = 0.010$, respectively) greater (4.7 kN•mm [50%] and 28.7 kN•mm [71%], respectively) for screws with deformed tips, compared with values for screws without deformed tips. Mean failure displacement was significantly ($P = 0.008$) greater (2.1 mm [52%]) for screws with deformed tips, compared with failure displacement for screws without deformed tips. Mean yield displacement and stiffness did not differ significantly between screws with or without deformed tips.

Maximum drill torque was positively correlated with yield variables; 83% of the variability in maximum drill torque was associated with variability in yield load (R^2, 0.83; $P = 0.040$) and displacement (R^2, 0.83; $P = 0.040$). Yield energy was positively correlated with total tap work (R^2, 0.88; $P = 0.020$). Maximum tap torque was positively correlated with failure load (R^2, 0.77; $P = 0.070$) and displacement (R^2, 0.77; $P = 0.070$). Total tap work was positively correlated with failure load (R^2, 0.77; $P = 0.070$), displacement (R^2, 0.77; $P = 0.070$), and energy (R^2, 0.94; $P = 0.005$).

Discussion

Insertion variables and mechanical properties during pushout testing for a headless tapered compression screw were compared between implantation in standard and oversize holes in a simulated lateral condylar fracture in equine MC3s. Enlargement of the diameter of the drill hole facilitated tapping; however, pushout strength of the headless tapered compression screw was reduced. Premature locking of the screw into the bone before the screw was completely inserted was detected in 3 specimens (1 in a standard hole and 2 in oversize holes). On the basis of these results, a standard hole size is recommended for repair of nondisplaced parasagital lateral condylar fractures of the metacarpus. During screw insertion, clinicians should be careful to ensure that screw threads follow tapped bone threads.

Drilling a hole with the oversize drill required 41 seconds more, compared with the amount of time required to drill holes with the standard drill, probably because of removal of more bone material during the drilling process. However, tapping was facilitated, probably because there was less bone material to cut for screw threads. Consequently, tapping oversized holes required less time (88 fewer seconds), less torque (42% less), less total work (70% less), and less positive work (70% less), compared with values when tapping standard holes. However, time required for screw insertion, torque for screw insertion, and work variables were not significantly affected by enlarging the diameter of the hole. High variability probably contributed to the lack of significant differences for screw insertion data.

The manufacturer of the headless tapered compression screw suggests that when excessive torque is encountered during screw insertion and the screw cannot be advanced to an appropriate depth, then the clinician should drill a deeper hole or use the oversized drill bit to drill a slightly larger hole. Because of its tapered design, redrilling of a hole that was already tapped should not affect holding power of the headless tapered compression screw because new threads will be created when the hole is retapped.[9] However, in the study reported here, it was subjectively more difficult to insert screws in oversize holes than in standard holes. One possible explanation is that it is more difficult to align screw threads with tapped bone threads in oversize holes than in standard holes. Affected screws cut new bone threads, which could lead to high screw-bone friction and premature locking of a screw into the bone. Premature locking of a screw into the bone before the screw is completely inserted has the undesired effect of impinging on the lateral collateral ligament. Because there is less of the screw engaging the parent bone fragment, pushout strength could be lower. Cross-threading of screws may be prevented by applying only light pressure as the screw is rotated into the tapped hole, rather than forcing a screw into the hole.

Maximum torque for insertion represented the maximal torque achieved when the screws were fully tightened. Maximum torque for insertion was not standardized in an effort to simulate surgical situations. In another study,[9] maximal torque required to strip the recessed screwdriver insert of the headless tapered compression screw was between 5.8 and 6.0 N•m. In the study reported here, 1 screw inserted in a standard hole required a maximal torque of 6.5 N•m before the screwdriver insert broke. When this occurred, the screw locked into position with the base of the screw protruding 2 mm above the epicondylar surface of MC3. This complication can probably be avoided by gaining experience with the maximum torque required for equipment failure. When it is perceived that application of maximum torque is being approached, the direction of the screw should be reversed (2 to 3 complete turns), and the screw can then be advanced farther by use of only one-eighth to one-quarter turns until the screw is properly positioned 1 to 2 mm below the surface of the bone.

Lack of bone fracture and screw failure with conical bone holes corresponding to the size and shape of the periphery of the screw threads for both diameters of holes support the hypothesis that screw-bone holding strength is related to the strength of the bone interface at the periphery of the screw threads. Because failure mode and size of the screw-bone interface were the same for screws in oversize holes and in standard holes, the amount of bone material supporting the screw threads affects pushout properties. There was less bone material supporting the screw threads for the oversize holes, which had less holding strength, compared with holding strength for the standard holes. The difference in screw-bone interface was most evident at the region surrounding the apex of the screw (Figure 3).

The 3 screws that had appreciable deformation of the tip during pushout testing had stronger mechanical properties during pushout. Maximum drill and tap torques exceeded 1.8 and 3.3 N•m, respectively, and total work integral exceeded 85.7 N•m•s. There were significantly higher values for pushout variables for the 3 screws with the deformed tips. All 3 screws had been inserted in standard holes.

Strong correlations were detected between some insertion variables and pushout properties. Maximum drill torque was highly correlated (> 80%) with yield load and yield displacement. Because maximum drill torque is expected to be higher in denser bone tissue, bone quality likely contributes to yield and screw properties during pushout testing. Interestingly, failure variables during pushout testing were correlated with maximum tap torque and total tap work. Reasons for the differences in variables associated with yield and failure are unclear. Perhaps the tapped threads were slightly larger than the screw threads, which may then have initiated pushout at the screw thread interface (yield) and completed pushout at the tapped thread interface (failure). Regardless, variables for drilling and screw insertion appear to be indicators of screw security in bone tissue.

The standard hole should be used to ensure optimum holding power in dense epiphyseal bone of MC3. Correct screw placement is important to maximize holding power. Clinicians should not rush during screw insertion to avoid equipment failure and premature locking of screws into the bone before the screws are completely inserted.

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a. Acutrak Equine, Acumed, Beaverton, Ore.
b. COE tray plastic, GC America Inc, Chicago, Ill.
c. 3.2-mm drill bit, Synthes, Paoli, Pa.
d. MTS TestStar, version 4.0C, MTS Systems Corp, Eden Prairie, Minn.
e. 4.5-mm drill bit, Synthes, Paoli, Pa.
f. Model 809, MTS Systems Corp, Eden Prairie, Minn.
g. Indico 100 series x-ray generator, Communications and Power Industries, Georgetown, ON, Canada.
h. Fuji film FCR 5000 plus, Fuji Film Medical Systems USA Inc, Stanford, Conn.

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