

Computed Tomography to Identify Preoperative Guidelines for Internal Fixation of the Distal Sesamoid Bone in Horses: An In Vitro Study

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Submitted December 2008

Accepted December 2009

DOI:10.1111/j.1532-950X.2010.00749.x

Objective: To assess the reliability of computed tomography (CT) to identify the direction of implant insertion for cortical screws along the longitudinal axis of intact (nonfractured) distal sesamoid bones.

Study Design: In vitro study.

Sample Population: Cadaveric paired equine forelimbs ($n = 16$).

Methods: Insertion of a cortical screw in lag fashion along the longitudinal axis of intact (nonfractured) distal sesamoid bones was evaluated in 2 groups (3.5 and 4.5 mm) of 8 paired limbs. In each group, the direction of the distal sesamoid bone was determined by CT (Equine XTC 3000 pQCT scanner). Screw placement was verified by specimen dissection. Implant direction was considered satisfactory if the entire screw length was within the distal sesamoid bone and not damaging the articular or flexural surfaces.

Results: In our sample and according to our criteria, the proportion of satisfactory direction of screws was 0.63 (5/8) for 4.5 mm implants, and 0.87 (7/8) for 3.5 mm implants.

Conclusions: CT is a useful imaging modality to identify anatomic landmarks for insertion of a 3.5 mm cortical screw in the distal sesamoid bone.

Repair of fractures of the distal sesamoid bone are challenging.^{1–4} Fractures occur in a various configurations, the most common being a slightly oblique sagittal fracture, medial, or lateral to the midline. Y-shaped fractures and other comminuted fractures are less frequent.⁵ Different treatments have been used including heel elevation by use of wedge-shaped shoe and rest,^{2,3,5–7} corrective shoeing associated with neurectomy,⁴ surgical removal of bone fragments,^{4,8} and internal fixation of sagittal fractures by means of a bone screw inserted in lag fashion.⁹ Precise implant insertion along the transverse axis of the distal sesamoid bone is essential to avoid penetration of the distal articular surface or the flexor surface. Intraoperative radiographic monitoring, fluoroscopy, and specially developed guide apparatus have been used to improve the accuracy of screw insertion.^{1,9–11} Surgical precision was shown to be better in vitro with computer-assisted surgery (CAS) in comparison with conventional technique.¹⁰

Recently, a peripheral quantitative computed tomography (pQCT) scanner was designed and used clinically by Desbrosse et al¹² The same authors used the pQCT to

determine anatomic landmarks for screw insertion in lag fashion in the distal phalanx.¹³ In the current study, our objective was to assess whether CT was a useful imaging modality to identify preoperative guidelines for insertion of cortical screws along the longitudinal axis of the distal sesamoid bone. Our research questions were: (1) what is the reliability of CT to assess the direction of the implant? and (2) is there a difference in insertion outcomes between 3.5 and 4.5 mm cortical screws?

MATERIAL AND METHODS

Specimens

Twenty paired forelimbs (6 Standardbred trotters, 4 Selle Francais) were collected from clinical cases euthanatized for reasons other than forelimb musculoskeletal abnormalities. After collection, limbs were disarticulated at the level of the carpometacarpal joint. The suspensory ligament and the flexor tendons were securely fixed to the third metacarpal bone (MC3), with a circumferential wire band threaded

through 2 holes created in proximal aspect of MC3, with the toe positioned in extension. Specimens were moistened, wrapped in gauze, sealed in plastic bags, and stored at -20°C . For study, limbs were thawed to room temperature. Shoes were removed. The hoof was carefully balanced, and cleansed of any debris. The hoof wall was lightly rasped to remove the stratum tectorium and any extraneous material. Each limb was identified by a number.

For the 10 pairs, 1 of each paired (matched) limb was randomly assigned by coin toss to a size of implant (3.5 and 4.5 mm groups). Two pairs were randomly chosen for training, and testing the surgical equipment and the dissection technique. The other 8 limb pairs were used to assess the reliability of the surgical technique to insert screws satisfactorily.

CT Scan and Calibration

An Equine XCT 3000 (Norland-Stratec Medical Sys., Pforzheim, Germany) was used. This unit uses translate-rotate multidetector technology, designed for pQCT. pQCT is a method of assessing bone mineral density that uses multiple cross-sectional X-rays to reconstruct a volumetric model of the bone density distribution. The X-ray tube operates at a maximum 60 kV with an anode current of 0.3 mA. The mean energy is 45 keV. The gantry has an opening of 300 mm diameter. The minimal longitudinal step width for scans is 0.01 mm over a full length of 350 mm. The system has been modified by the authors to be used both

horizontally and vertically¹²; wheels and brakes have been added (Fig 1A). The scanner weighs 200 kg, is mobile and can easily be moved within the hospital.

The system uses software (Stratec, Pforzheim, Germany) to control the scan, display the images, measure distances, and bone density. 3D images could be obtained using other software called VolView (Kitware, New York, NY). The CT scan is calibrated before use with a phantom provided by the manufacturer.

CT Scanning

A horizontal dorsopalmar radiograph of all limbs was made to assess lateromedial foot balance (80 kV, 5 mAs, General Electric Medical System, Paris, France). Trimming was performed to improve lateromedial balance. The objective was to obtain as much parallelism as possible between the transverse axis of the distal sesamoid bone and a horizontal line on the horizontal dorsopalmar radiograph. Balancing is required to ensure that, as much as possible, once the limb is fixed on the bottom plate of the holding device within the CT scan (Fig 1B), the CT slices are parallel to the transverse axis of the distal sesamoid bone. Two 3 cm long, 2 cm wide pieces of a radio-opaque drain (Multitubular Drain, Porges, France) were glued with cyanoacrylate (Colle Cyanoacrylate, Auchan, France) on each side of the hoof, parallel to the coronary band, 1.5 cm below it at middistance between its dorsal and palmar aspects, over the projection area of the distal sesamoid bone

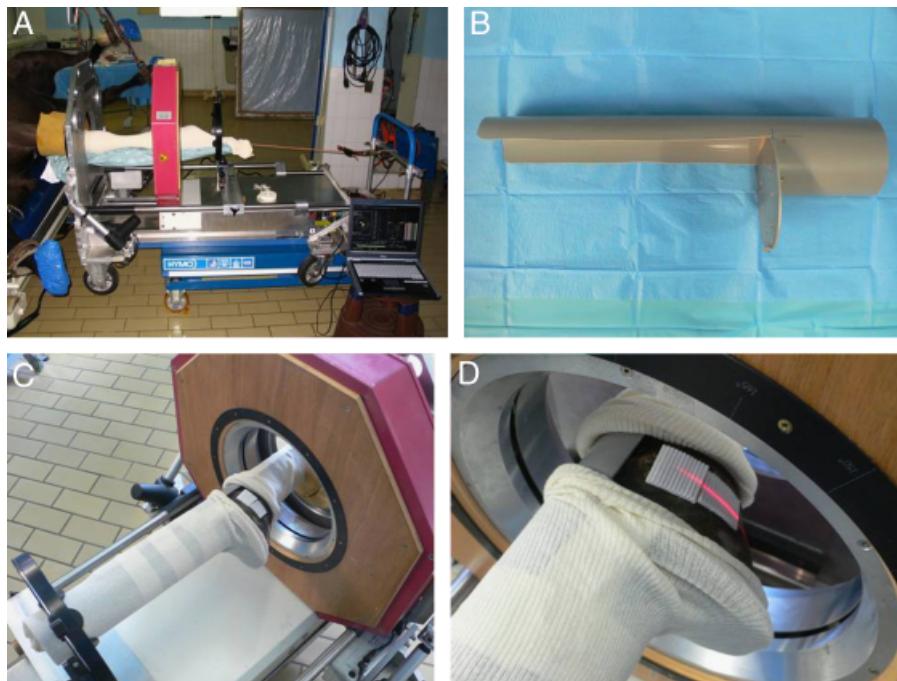


Figure 1 (A) The computed tomographic scanner can be used under general anesthesia and can be moved easily through the surgical theatre. (B) Splint used to maintain the limb within the gantry. (C) The distal aspect of the forelimb positioned through the gantry. (D) The red line of the laser is visible and intersects the radiopaque tubules. The points at the intersection, on each side of the hoof wall, will serve as landmark for the guiding device at surgery.

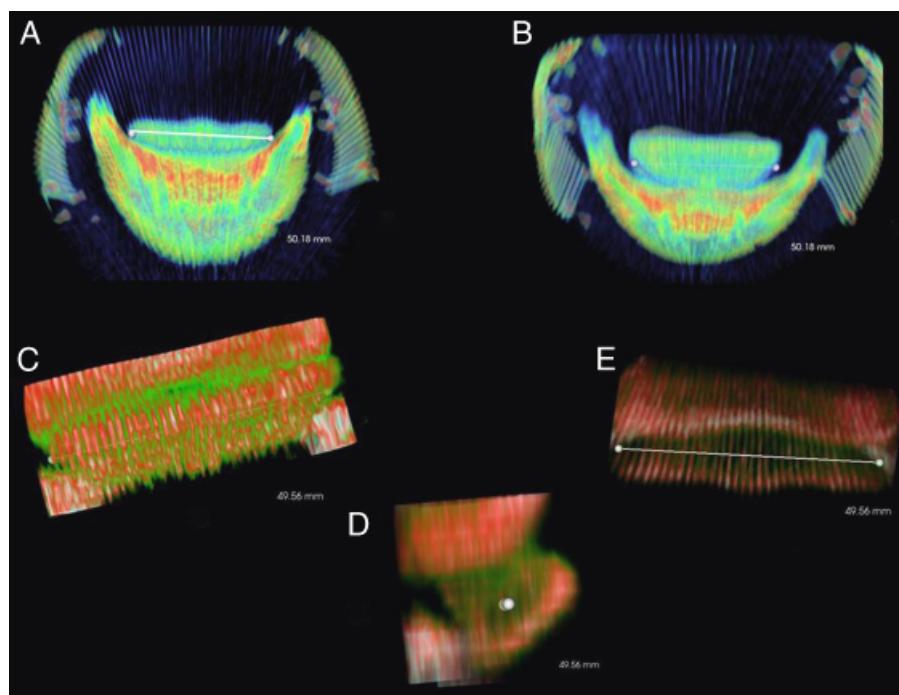


Figure 2 Two-dimensional images displaying the distal sesamoid (navicular) bone in different planes. The radiopaque tubules are visible on both sides of the hoof wall (A, B). A line is drawn to indicate the axis of the virtual screw, and the segment of that line included between the lateral and the medial aspects of the distal sesamoid bone will determine screw length. Cropping allows isolate the distal sesamoid bone to improve observation (C–E).

(Fig 1C). Each tubule of the multitungular drain was 2 mm in diameter. The limb was positioned through the gantry of the Equine XCT 3000 as it would be the case for a living animal undergoing surgery. A preliminary scan was made to plan the slices. Ten contiguous 2 mm transverse CT slices were made, parallel to the solar surface, in a proximal to distal direction including the distal sesamoid bone (Fig 1D).

Identification of Anatomic Landmarks for Implant Insertion (Figs 2–4)

Because it is difficult to create a standardized fracture of the distal sesamoid bone within the hoof, we assumed a virtual fracture plane crossing the bone at its midpoint with a 90° relationship to the longitudinal axis of the distal sesamoid bone. The distal sesamoid bone was observed in 3 dimensions with Volview (Fig 2) to choose the appropriate location of the screw according to the following criteria: the virtual screw should traverse the bone in its core, without penetrating the articular or flexor surfaces. The “cropping” function of the 3D software was used to display several sagittal sections of the distal sesamoid bone and to confirm that the virtual screw was consistently crossing each sagittal slice of the bone in its center (Fig 3A and B).

Once the line that represents the axis of the virtual screw was drawn with the 3D software, the length of the bone was assessed. Then the line was prolonged until it intersected the radiopaque tubules. Intersects were identified on each side of the hoof wall on the 3D image and

indicated by a red dot (Fig 3C and D). Other useful distances were also computed: the distance between the hoof wall and the distal sesamoid bone, and the distance between the hoof wall and the virtual fracture line.

The slice (2D image) that contained the intersections (red dots) was identified, and its number was noted (Fig 4). Each slice number is associated with a position along the axis of translation of the gantry, called Z position (Fig 4). The Z position is provided by the software. Once this data is input in the system, the CT is able to reposition itself at the exact level of the slice corresponding to that Z position. The slice corresponding to the Z position where the CT scan stops is indicated by the laser beam of the scanner (Fig 1D).

The CT was programmed to position its laser beam according to the Z position. Then the intersections of the tubules with the laser beam were marked with a pen on each side of the hoof. Notches in the hoof were created on those marks with a 2 mm drill bit and would constitute the landmarks for the placement of the guiding device at surgery.

Surgical Procedure

Limb specimens were held by an assistant (SG), on the surgical table medial side down. The procedure was performed by 1 surgeon (JMV). It was decided that, at surgery, no control radiograph would be taken and that no screw would be changed if it appeared to be too short and loose. This was considered essential to assess the effectiveness of

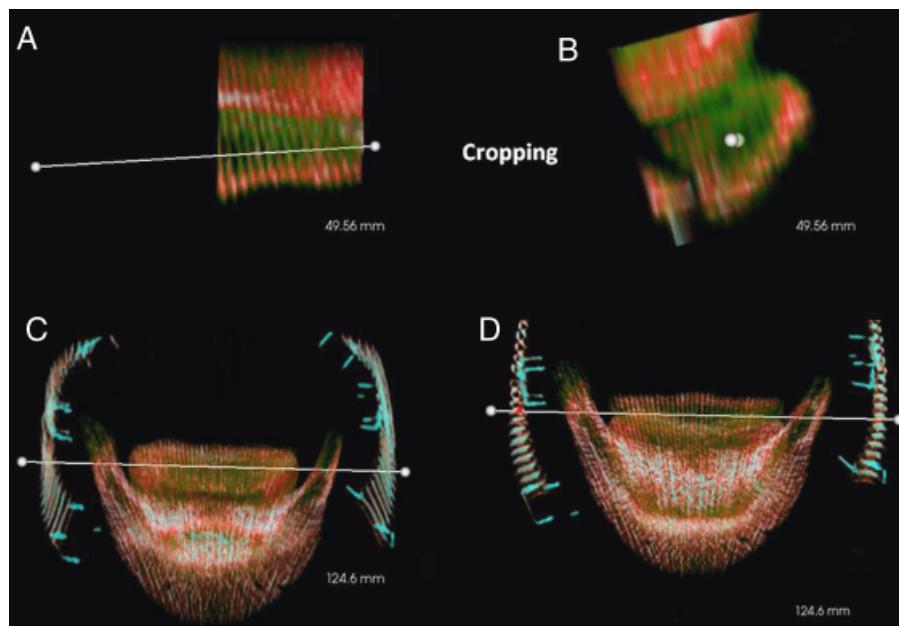


Figure 3 The cropping function can also be used to display several sagittal views to confirm that the virtual screw is traversing the bone in its core (A and B). The line is then prolonged until it intersects the radiopaque tubules (C). The intersections are indicated with dots (D).

the technique. The procedure was composed of 6 surgical steps in both screw groups (3.5, 4.5 mm; Table 1, C clamp—Fig 5).

Data Evaluation

The foot was dissected and the distal sesamoid bone was isolated. Gross anatomy was evaluated by another surgeon (R.P.) who was asked to inspect closely the articular and flexor surfaces, and the medial and lateral angles. A grading scale was used. Score 1 was “ideal” = the screw would

traverse the bone along its longitudinal axis and without significant damage to important clinical structures such as the articular surface or the flexor surface. Score 3 was “not acceptable” = screws were damaging those structures, and score 2 was intermediate (“not ideal”) where screws were not penetrating but only deforming the flexor or articular surface. Only scores of 1 were considered “satisfactory.” Scores of 2 and 3 were considered “unsatisfactory” (Fig 5).

Statistical Analysis

The analysis included assessment of scores of position of the screws. The difference in success between the 3.5 and 4.5 mm screws were analyzed using McNemar’s test and odds ratios (OR) were reported along with their 95% confidence intervals (95% CI).

RESULTS

For 3.5 mm implants, 7 of 8 screws were satisfactorily inserted compared with 5 of 8, 4.5 mm implants. Use of 3.5 mm screws was associated with an increased odds of good outcomes; however it failed to reach statistical significance, OR = 4.2 (95% CI, 0.33–53.12; $P = .27$).

DISCUSSION

Our results showed that the pQCT scanner represents a practical alternative to fluoroscopy or CAS to identify the implant direction for screw insertion in the distal sesamoid bone.^{9,10} Results are encouraging as 7 of 8, 3.5 mm screws were satisfactorily positioned and did not penetrate the

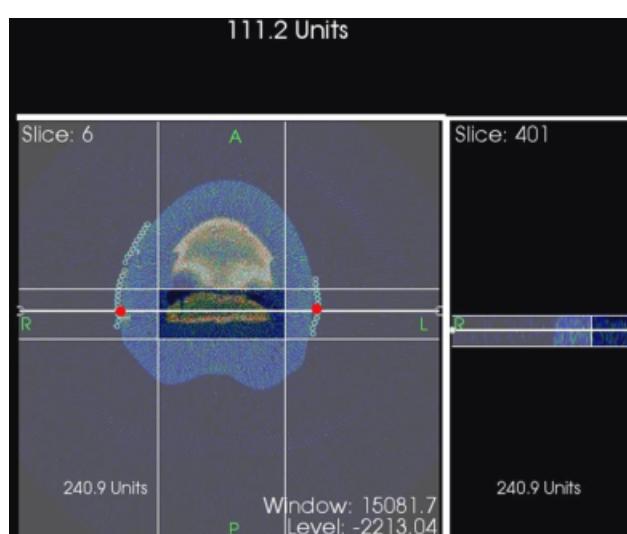


Figure 4 The red dots are identified on the transverse slice and the slice number is identified.

Table 1 Surgical Steps and Equipment

Surgical Steps	Technique Description
1. Initial drilling of the horn	The clamp was positioned on the foot according to the landmarks that had been drilled into the hoof wall. A 4.5 mm diameter drill bit was used to drill through the hoof wall surface to the distal sesamoid bone
2. Gliding hole	The hole in the horn was flushed. For 4.5 mm screws, the drilling was continued with the 4.5 mm drill bit and the C clamp to the level of the virtual fracture line. For 3.5 mm screws, a drill sleeve (4.5 mm external diameter, 3.5 internal diameter, custom made) was inserted in the hole and a 3.5 mm drill bit was used to create the gliding hole
3. Thread hole	In the 4.5 mm group, a drill sleeve (4.5 mm external diameter, 3.2 mm internal diameter) and a 3.2 mm drill bit were used to create the thread hole. In the 3.5 mm group, a drill sleeve (3.5 mm external diameter, 2.5 mm internal diameter) were used
4. Tapping	The thread hole was tapped with a 3.5 or 4.5 mm tap
5. Final drilling of the horn	A hole was drilled through the hoof wall to the bone to allow passage of the screw head. A 6.5 mm diameter drill bit was used for 3.5 mm screws. An 8 mm diameter drill bit was used for 4.5 mm screws
Countersinking was not performed	
6. Screw insertion	A screw was selected according to the length that had been determined by CT and was inserted. As a whole range of different screw lengths is not supplied by Synthes, the next shorter screw was selected when the appropriate implant was not available

CT, computed tomography.

articular or flexor surface with the technique we described. Nevertheless, even 1 failure with the 3.5 mm implants remains clinically unacceptable, and results with 4.5 mm implants were less satisfactory still. Although not statistically significant, the difference between the 4.5 and 3.5 mm outcomes was mainly related to screw diameter as, despite insertion in the correct direction, they more commonly deformed the flexor or articular surface, which would have likely caused dramatic lameness.

Considering the fact that the badly positioned screw was parallel to the axis of the distal sesamoid bone (Fig 6), indicating that this might be an error of slice identification, it is possible that this may have been avoided if radiographic control had been used. However, our aim was to identify anatomic landmarks without any method of intraoperative imaging to assist with proper screw positioning or alignment. After that, the screws were essentially inserted blindly. Because control radiographs could be used

clinically, inclusion might have given a more accurate reflection of their utility, possibly improving the outcome. However, if screw direction is altered based on intraoperative imaging, errors may still occur if radiographic projections are not accurately aligned with the central beam parallel to the long axis of the bone (in the lateromedial projection) and the same in all the other projections. Once the clamp has been redirected new radiographs should be taken, which, with the drill inserted, can be quite difficult. Also, once the horn has been drilled, it becomes very difficult to reposition the drill. Thus this is essentially a "one shot" procedure. Nevertheless, we believe that it would be prudent when using this CT technique to also use radiographic control to double-check the landmarks before drilling. Clinically, we would probably perform this double-checking preoperatively with the technique we have used before for distal sesamoid bone and distal phalanx fractures.¹³ A radiopaque marker (lead shot) would be placed along 1 lateral aspect of the hoof, where a 1st landmark has been identified with CT. A metallic ring would be placed on the opposite side of the hoof, on the 2nd identified landmark. A lateromedial radiographic projection would be made to confirm that the lead shot appears as the center of circular target (the ring) on the radiograph.

Study Limitations

Weaknesses of our study are the small sample size, which limited statistical power. The difference between the use of 3.5 and 4.5 mm screws was not statistically significant despite the apparent better results obtained with the 3.5 mm implants. Furthermore, other criteria might have been considered such as the position of the screw head at insertion, penetration of the screw at the far cortex, and screw length. Our results might be biased by lack of availability of adequate sized implants; 3.5 mm screws are only available in a limited range of lengths > 48 mm (50–65 mm, in 5 mm increments). Thus the optimal screw length may not be

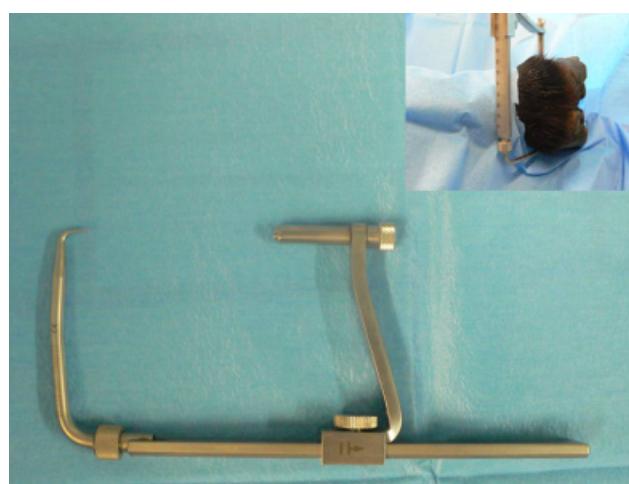


Figure 5 Custom clamp used to guide drilling (C-clamp, Synthes, Etapes, France).

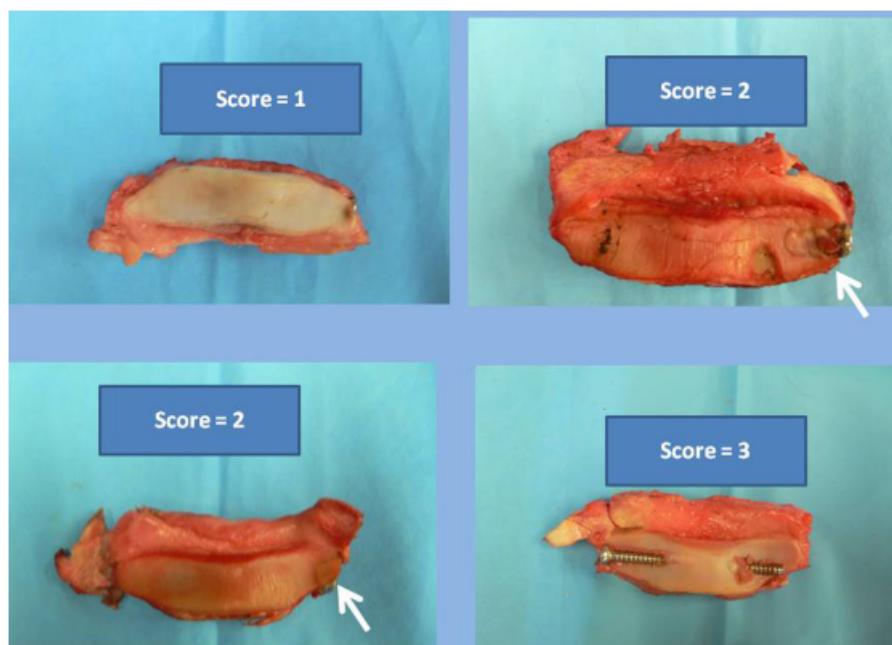


Figure 6 The scoring system is illustrated. No visible screw was an “ideal” outcome (score = 1), slight bulging (arrows) was a “not ideal” outcome (score = 2), and a “not acceptable” outcome (score = 3) was given when the screw was causing damage to important structures such as the articular or flexor surfaces. This figure shows also the 3.5 mm screw that was badly inserted in this study.

available, and screw choice may reflect availability rather than length measured with CT. Other in vitro studies have investigated the use of 3.5 implants for internal fixation of the distal sesamoid bones, but have not reported this technical issue. For those reasons, we have focused our report on only 1 outcome measure (screw direction) that was easy to assess by grossly. Finally, we only tested truly sagittal nondisplaced virtual fractures, so we do not know how the technique would perform with fracture gap and fragment displacement. Future in vitro studies should investigate the application of the technique on artificially created and standardized fractures.

A major advantage of the technique we report is that anatomic landmarks can be identified, and double-checked by radiography, preoperatively. This could be performed on the standing horse.¹³ Though this surgery remains difficult, preoperative planning might reduce the expertise that is required for the surgery and screw placement. The images collected during this study could also be used for virtual training before future repair of a distal sesamoid bone fracture. Identification of landmarks can also be performed on the recumbent horse before surgery. Aseptic preparation can be performed before or after scanning in clinical cases.

We concluded that pQCT could be used to assess anatomic landmarks (site and direction of implant) before insertion of a cortical screw for the treatment of a fracture of the distal sesamoid bone with 3.5 mm screws preferable to 4.5 mm screws. It would be advisable to double-check the landmarks obtained with CT by conventional radiography. Importantly, surgeons should be aware that the availability

of adequate length screws may be of concern. By taking these factors into consideration, CT scan assessments could be used optimally. However, further studies with larger numbers and using living animals are warranted.

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