Veterinary Surgery
38:373–379, 2009

Use of Computed Tomography in Standing Position to Identify Guidelines for Screw Insertion in the Distal Phalanx of Horses: An Ex Vivo Study

JEAN-MICHEL E. VANDEWEERD, DVM, DES, Cert ES (Soft Tissue), ROLAND PERRIN, DVM, Diplomate ECVS, THOMAS LAUNOIS, DVM, Diplomate ECVS, LAURENT BROGNIEZ, DVM, SIMON GEHIN, DVM, PETER D. CLEGG, MA, VetMB, Cert EO, Diplomate ECVS, MRCVS and FRANCIS G. DESBROSSE, DVM, Diplomate ECVS

Objectives—To compare the precision of radiography and computed tomography (CT) preoperatively in the standing position for identification of guidelines for screw insertion in the distal phalanx, and to identify whether standing CT might improve operative time compared with preoperative radiographic planning.
Study Design—Experimental ex vivo study.
Animals—Cadaveric equine thoracic limb pairs (n = 10).
Methods—Insertion of a 4.5 mm cortex screw in lag fashion into an intact distal phalanx was evaluated in 2 groups (n = 10) of cadaveric equine thoracic limbs. In 1 group, the site, direction, and length of the implant were determined by radiography, and in the other group, by CT. Accuracy of screw placement was verified by specimen dissection. Outcomes were (1) absence of penetration of the articular surface, the solar surface, or the semilunar canal (2) appropriate length and direction of the screw. Surgical time was also measured.
Results—No screw penetrated the articular surface, the solar surface, or the semilunar canal in either group. CT was more accurate to identify guidelines for screw insertion (U = 23.50, $P = .049$). With CT, surgical time (mean, 7.7 minutes) was significantly shorter (U = 0.000, $P = .000$) than with radiography (mean, 12.7 minutes).
Conclusion—Standing CT can be used to accurately determine anatomic landmarks for screw insertion in lag fashion in sagittal fractures of the distal phalanx.
Clinical Relevance—This study has a clear clinical relevance for improved internal fixation of sagittal fractures of the distal phalanx.

INTRODUCTION

FRACTURES OF the distal phalanx occur more commonly in the thoracic limb and in racing breeds, particularly Standardbreds,[1–6] in various configurations that have been classified into 7 types.[3] Type III (sagittal) fractures account for 3–4% of fractures of the distal phalanx and remain a challenging problem for repair.[4,5,7] Although articular type III fracture may heal well if treated conservatively in young horses,[8] internal fixation using a screw inserted in lag fashion is recommended to limit development of osteoarthritis in horses ≥ 3 years.[9,10]

Precise implant insertion along the transverse axis of the distal phalanx is essential.[11] Screw length should be determined accurately so that it reaches the far surface of the bone without contacting the sensitive lamellae; however, this cannot be done accurately from dorsopalmar radiographs because of the dome shape of the distal phalanx.[3,11] The screw should also be inserted

From Clinique Equine Desbrosse, Saint-Lambert-des-Bois, France; The Faculty of Veterinary Medicine, University of Liège, Liège, Belgium; and the Department of Veterinary Clinical Science and Animal Husbandry, The University of Liverpool, Leahurst, UK.
Address reprint requests to Jean-Michel E. Vandeweerd, DVM, DES, Cert ES (Soft Tissue), Clinique Equine Desbrosse, 18 rue des champs, Saint-Lambert-des-Bois, France. E-mail: jmvdw@hotmail.fr.
Submitted April 2008; Accepted July 2008

0161-3499/09
doi:10.1111/j.1532-950X.2009.00502.x

perpendicular to the fracture plane to prevent fragment displacement during screw tightening and the gliding hole (GH) should just cross the fracture line to ensure fixation in lag fashion while leaving the longest possible thread length to ensure solid compression. Further, anatomic structures such as the articular surface and the semilunar canal should be avoided.[7,11,12]

Numerous intraoperative radiographs are necessary to determine the precise location of screw position and to guide placement.[13] Radiographic monitoring during surgery may be time consuming and resulting in increased radiation exposure of personnel and increased duration of general anesthesia. Fluoroscopy and specially developed guide apparatus have been used to improve the accuracy of screw insertion. Andritsky et al[7] demonstrated that computer assisted surgery (CAS) was more accurate than conventional technique to insert screws in the distal phalanx and would result in improved clinical success; however, the technique is expensive and not readily accessible.[14]

A technique for computed tomography (CT) of the foot in the standing horse with a pQCT scanner (XCT 3000, Norland-Stratec Medical Sys., Pforzheim, Germany) has been reported (Fig 1).[15] We have previously used conventional radiography to both identify surgical landmarks preoperatively and to assess intraoperative drilling and screw placement in cases of sagittal P3 fracture. In the current study, we hypothesized that standing CT with the XCT 3000 would be more accurate than radiography for preoperative planning of surgical guidelines (site, direction, and length of implant) for screw insertion into the distal phalanx in horses and require less surgical time.

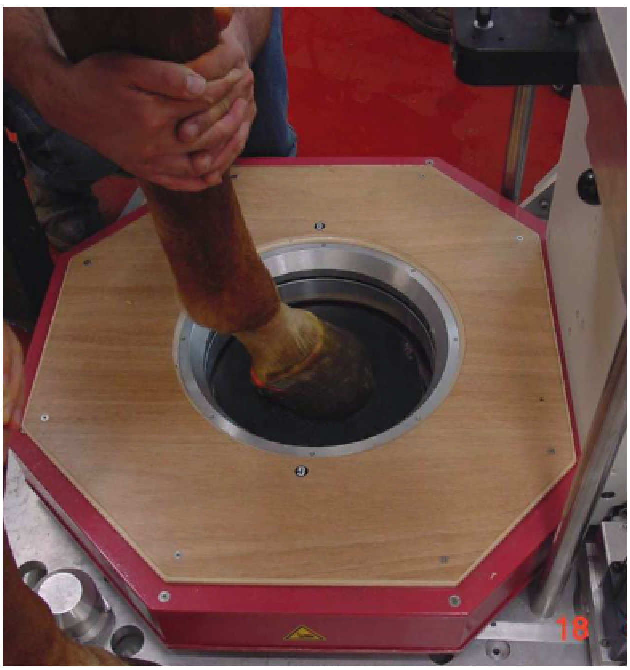

Fig 1. Computed tomography of the foot in standing position.

MATERIAL AND METHODS

Specimens

Ten paired forelimbs were collected from skeletally mature horses (3–18 years) admitted to our clinic and euthanatized for reasons unrelated to forelimb musculoskeletal abnormalities. They were a Shetland, an Arab, a Welsh Section B, 2 Standardbred trotters, and 5 Selle Français. After collection, limbs were disarticulated at the level of the metacarpophalangeal joint, sealed in plastic bags and stored at −20°C. One limb of each pair was randomly assigned to each imaging technique (CT group or Radiography group) and pairs were randomly ranked to determine the order of experimental use. Furthermore, within each pair, the imaging/surgical technique was alternated to avoid systematic use of one technique before the other. Limbs were kept frozen for imaging and thawed to room temperature for surgery. Shoes were removed and the hoof was carefully balanced, and cleansed of any debris.

Surgical Landmarks

Because it is difficult to create a controlled mid-sagittal fracture in cadaveric feet without disrupting the hoof capsule and supporting soft tissue structure, we assumed a fracture plane through the distal phalanx that was perpendicular to the solar surface. The desired direction of the screw was therefore parallel to the solar surface and perpendicular to the long axis of the limb. Each frozen limb was kept in physiologic standing position.

Radiography Group

The hoof wall was wrapped with 5 cm wide tape (Leukoplast, Stella, Belgium). Horizontal dorsopalmar projections were made to assess lateromedial foot balance and to assist foot trimming. A radio-opaque marker (lead shot) was placed along the lateral aspect of the hoof, and lateromedial radiographic projections were made (General Electric Medical System, Buc, France; 80 kV, 5 mA s). The beam was centered on the position of navicular bone and angled at a tangent to the bulbs of the heels. Angulation of the beam was modified and the radiograph was repeated if the lateral and medial aspect of the navicular bone were not superimposed. The surgeon aimed to simulate with the lead shot a virtual screw, midway between the articular margin and the semilunar canal, on a line parallel to the dorsal surface of the distal phalanx.[3,11] Once the lead shot was located in the correct position, a metallic ring was taped on the opposite side of the hoof, so that the lead shot appeared as the center of circular target on the lateromedial projection. A notch was made with a 2 mm drill bit on each side of the hoof wall, 1 through the metallic ring and the other through the mark left by the lead shot on the tape (Fig 2).

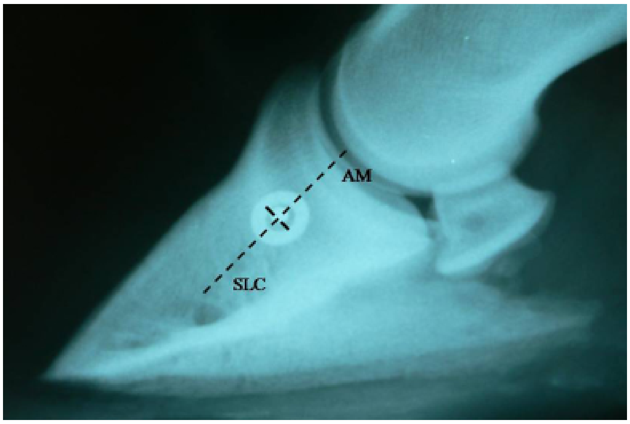

Fig 2. Identification of surgical landmarks by radiography. The lead shot appeared as the center of the target on a lateromedial projection, close to midway between the articular margin (AM) and the semilunar canal (SLC) on a line parallel to the dorsal surface of the distal phalanx.

CT Group

A horizontal dorsopalmar projection was made to assist foot trimming and balancing. The limb was placed through the gantry of a pQCT scanner (XCT 3000, Norland-Stratec Medical Sys.) in the same position as for CT in a standing horse.[15] Two 5 cm long, 2 cm wide pieces of a radio-opaque drain (Multitubular Drain, Porges, Sarlat, France) were glued with cyanoacrylate (Colle Cyanoacrylate, Auchan, La Verrière, France) on each side of the hoof, parallel to the sole, and centered 1.5 cm below the coronary band at mid-distance between its dorsal and palmar aspects. A scout image was made to plan the slices. Twelve contiguous 2 mm transverse CT slices were made in a distal to proximal direction beginning at the level of the distal aspect of the drains, including the articular margin and semilunar canal to be able to determine that the site chosen was midway between them. 3D images were created with Volview software (Kitware, New York, NY). The distal phalanx could be displayed in as many different views as needed to assess the appropriate axis for the implant. The screw should cross, perpendicular to the sagittal plane, midway between the articular margin and the semilunar canal, far enough from the sites of insertion of the collateral ligaments, the coffin joint, and the solar surface (Fig 3).

Once the ideal direction was determined, the intersections between the imaginary axis of the screws and the drains were located and materialized with white dots on the 3D projection. The slice including the dots was then identified in Volview (Fig 3). Then it was displayed in measure mode in the XCT 3000 software. The distance from the hoof to the pedal bone (W) and the width of the pedal bone or length of the screw (S) were measured (Fig 4). Surgical landmarks were identified at the intersection of 2 lines obtained by counting the divisions on the transverse axis of the marker (line 1) and by identifying the slice with the laser pointer of the CT scan (line 2). Those landmarks were marked with a pen on specimens (Fig 5). Notches in the hoof were created with a 2 mm drill bit.

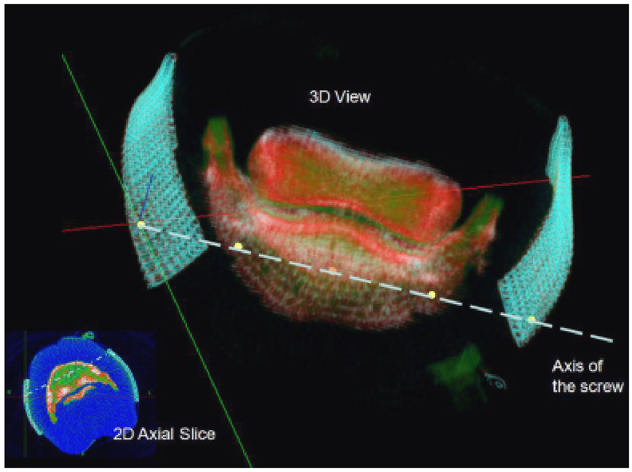

Fig 3. Identification of surgical landmarks by computed tomography (CT). The direction of the screw was determined from the 3D view of the pedal bone. This figure shows one of the many possible 3D views. Markers (white dots) were positioned along the direction of the virtual screw. The tubular markers were visible on each side of the hoof. The 2D axial CT slice that included the dots was identified.

Surgical Procedure

Equipment for screw insertion included conventional AO instruments and a special clamp used to guide drilling (C-clamp, Synthes, Paoli, PA). Limb specimens were held by an assistant (S.G.), on the surgical table, in an extended position, medial side down. The procedure was performed by 1 surgeon (J.M.V.). 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 ensure a valid comparison between techniques.

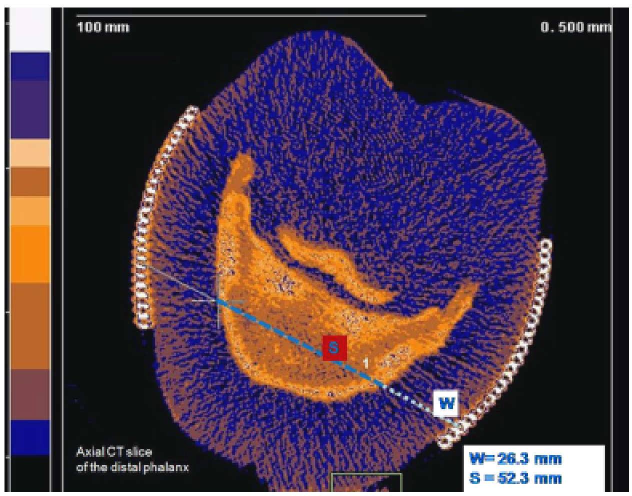

Fig 4. Screen shot of the Equine XTC software. The distance from the hoof to the bone (W) and the length of the screw (S) were measured.

Fig 5. Identification of surgical landmarks in the computed tomography (CT) group at the intersection of the division of the marker (line 1) and the horizontal plane of the CT slice that includes the virtual screw (line 2).

Radiography Group. Figure 6. The width of the hoof in the horizontal plane of drill site was measured with calipers according to the landmarks previously drilled in the horn (D) and the clamp positioned according to the landmarks drilled into the hoof wall. A 4.5 mm hole was drilled through the hoof wall surface to the distal phalanx. As there was no asymmetry between medial and lateral hoof walls on preoperative radiographs, the depth from the outer hoof wall to the bone was determined (W), doubled, and subtracted from the measurement of the hoof at that location. This calculation was called

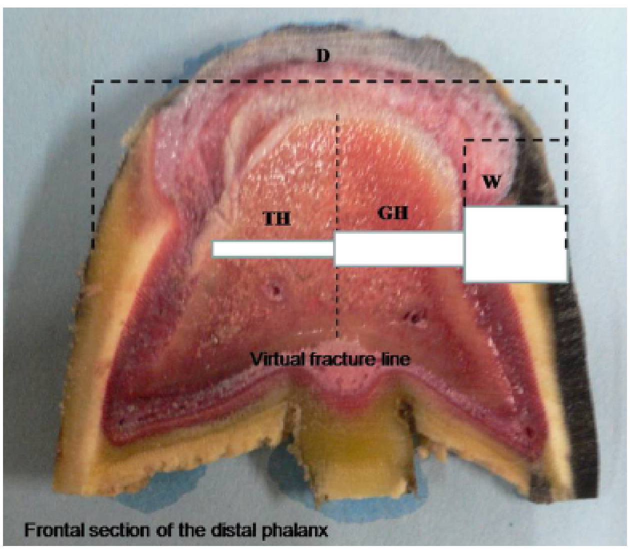

Fig 6. Distances used at surgery in the radiography group: depth from the outer hoof wall to the bone (W), measurement of the hoof at that location (D), calculated length of the screw ($L_c = D-2W$), distance from the hoof wall to the fracture line [$W + (L_c/2)$]. The threaded hole (TH) and gliding hole (GH) are shown.

the calculated length of the screw ($L_c = D-2W$).[7] The GH was drilled to the virtual fracture line. The distance from the hoof wall to the fracture line was equal to [$W + (L_c/2)$]. The drill sleeve was then inserted to assist with placement of the thread hole (TH). A concentric 3.2 mm TH was drilled through the remaining bone. The calculated screw length was used to estimate the length of the TH and minimize the soft tissue penetration on the far side. A 14 mm diameter hole was then drilled through the hoof wall to the bone to allow placement of the screw head. Countersinking was performed and kept to a minimum (1 rotation). A depth gauge was inserted to assess necessary screw length, called the measured screw length (L_m). This measurement (L_m) was compared with the calculated screw length (L_c) and the average ($L_m + L_c/2$) was used to select the actual screw length.[7] The TH was tapped and the selected screw was inserted. Total surgical time was recorded.

CT Group. The clamp was placed over the landmarks drilled into the hoof. The distances and lengths measured with CT were used. A 4.5 mm hole was drilled on a distance equal to W. The GH was drilled a distance equal to S/2. The drill sleeve was inserted and a 3.2 TH was drilled through the far half of the bone on a distance equal to S/2. An 8 mm hole was then drilled through the hoof wall to the bone to enable countersinking. The TH was tapped and a screw equal to S was inserted. The surgical time was measured.

Data Evaluation

Hoof capsule and soft tissues were removed from each limb. The distal phalanges were identified by code only without any indication of the surgical technique used. Gross anatomy was evaluated by another surgeon (R.P.) who was asked to assess (Fig 7A–D): if the inserted screws penetrated the articular surface (outcome 1a) and the solar surface (outcome 1b); if the axis of the screw was parallel to a reference line (ab) drawn perpendicularly to the virtual fracture line (i.e. parallel to a line drawn through the intersects of the frontal plane of a virtual section of the phalanx with the edges of the distal phalanx [cd]) from the point of insertion of the screw in the hoof wall (outcome 2a, B in Fig 7); if the axis of the screw was parallel to a reference line (ef) tangent to the articular border when the specimen of the distal phalanx is viewed in a proximodistal direction (outcome 2b, C in Fig 7); if the screw was of the appropriate length, which meant if the far end of the screw protruded minimally beyond the bone and if there was penetration of the far cortex (outcome 3). After the screws were removed, phalanges were sectioned sagittally and parasagittally and the surgeon was asked to assess if the screw hole was penetrating the semilunar canal (outcome 1c) and if the screw was in a central position in the distal phalanx between the semilunar canal and the articular, dorsal, and solar surfaces (outcome 4, D in Fig 7).

For outcomes 1 a–c, a dichotomized answer was expected (yes or no). For outcomes 2–4, a grading scale was used. The direction of the screw (outcome 2a and 2b) was graded from 1 to 4: with 1 = excellent (implants positioned parallel to the reference line), 2 = good (implant within 3–5° of parallel to the reference line), 3 = poor (implant within 5–7° parallel to

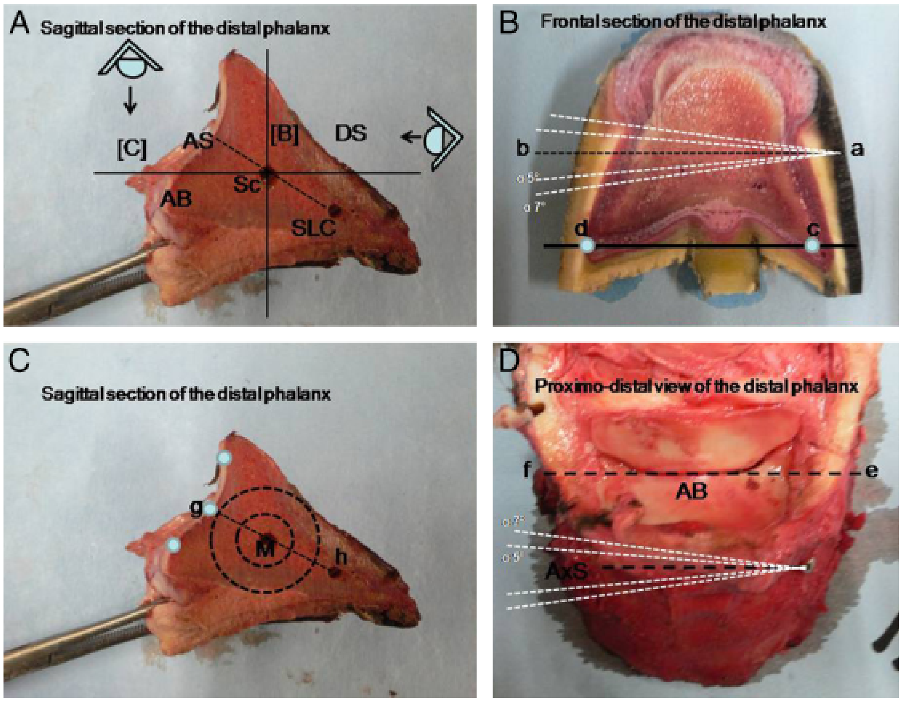

Fig 7. Illustration of the scoring system. (A and D) Sagittal sections through the distal phalanx showing the landmarks used to assess the position of the screw hole (Sc) in relation to the semilunar canal (SLC), articular surface (AS), dorsal surface (DS), and articular border (AB) (outcome 4). (A) Shows also how (B) and (C) should be viewed. (C) Frontal section showing how the direction of the screw was compared with a line drawn perpendicularly to the fracture line from the point of insertion of the screw in the hoof wall (outcome 2a). (D) Proximo-dorsal view of the foot after dissection showing how the axis of the screw (AxS) was compared with a reference line tangent to the articular border of the distal phalanx (outcome 2b).

the reference line), and 4 = bad (implant $>7°$ from the reference line). Angles were measured with a goniometer. For outcome 3, the optimal screw length was determined by adding the depth of the screw head to the length of the hole drilled in the pedal bone (measured with a depth gauge after removal of the screw and therefore taking countersinking into account). Screw length was classified as excellent (= 1) if it was not >1 mm longer than the optimal length, good (= 2) if it was 2 mm longer, and poor (= 3) if it was >2 mm longer. Screws that were shorter than the optimal length but did reach and penetrate the far cortex were classified as good (= 2). Screws that did not penetrate the far cortex of the bone were classified as bad (= 4). Similarly, the position of the screw (outcome 4) was graded from 1 to 4 according to the more or less central position of the hole in the sagittal section of the distal phalanx (D in Fig 7): a score of 1 was given when the screw was positioned at mid-distance (point M) between the articular surface and the semilunar canal on a line drawn from the later to the closer aspect of the joint surface (gh), a score of 2 was attributed when the screw was positioned in a circle centered on M and with a circumference equal to the mid-distance from M to the dorsal surface of the distal phalanx, a score of 3 was given when the screw was positioned in a circle centered on M but where the circumference equals the distance from M to the dorsal surface, and a score of 4 was attributed for any other position.

Statistical Analysis

Scores for outcomes 2, 3, and 4 were summated to obtain a global score for each limb. Means and medians for the total scores, for surgical time, and for each individual outcome were generated. Assumption of normality of the data was not met so the medians were compared using the nonparametric Mann–Whitney test. All analyses were performed using commercial computer software SPSS (SPSS France, Paris-La-Défense, France). A *P*-value $<.05$ was considered significant. Pearson's correlation coefficient r was used to measure the size of the effect.[16]

RESULTS

No screw penetrated the solar surface, semilunar canal, and articular surface in either group (outcomes 1 a–c). In the CT group, 1 screw was too short and did not penetrate the far cortex. In the radiography group, 5 screws did not penetrate the far cortex in the bone at insertion and 1 screw incompletely penetrated the far cortex. There was a significant difference between the 2 groups for total scores, with CT being more accurate than radiography for screw insertion (U = 23.50,

Table 1. Comparison of Mean and Median Total Scores, Times and Scores for Outcomes 2–4 (n = 20)

	Radiography (n = 10)			CT (n = 10)			Mann–Whitney
Outcome	Mean	Median	Mean Rank	Mean	Median	Mean Rank	*P*-Value
2a. Direction of the screw from a parallel to the solar surface	1.3	1.0	9.7	1.4	1.0	11.30	.628
2b. Direction of the screw from a parallel to the articular border	2.0	2.0	13.30	1.3	1.0	7.70	.038*
3a. Length of the screw	3.0	4.0	13.15	1.5	1.0	7.85	.033*
4. Position of the screw	1.3	1.0	9.00	1.6	2.0	12.0	.370
Total scores	7.60	7.50	13.15	5.80	5.50	7.85	.049*
Time (min)	12.7	12.0	15.5	7.7	8.0	5.5	.000*

*Significantly different at $P < .05$.

$P = .049$, $r = -0.45$; Table 1). Scores for outcome 2b (direction of screw from a parallel to the articular border) and 3a (screw length) were significantly different, with the median rank of scores significantly lower (better precision) for the CT group than for the radiography group ($U = 22.00$, $P = .038$, $r = -0.52$, for outcome 2b; $U = 23.50$, $P = 0.033$, $r = -0.49$ for outcome 3a). For the conventional technique, mean surgical time was 12.7 minutes (range, 10–15 minutes), whereas it was 7.7 minutes (range, 6–9 minutes) for the CT technique. Surgical time was significantly shorter with CT assisted technique ($U = 0.000$, $P < .05$, $r = -0.87$).

DISCUSSION

Our study population included various breeds so the techniques were investigated in distal phalanges of varying size. Thus, the conclusions should be reasonably generalized across horse populations. Working with paired limbs ensured matching of age, gender, and size. Randomization and counterbalancing reduced sources of systematic variation other than the intervention, such as training and learning curve; however, other outcome criteria and other scales might produce different results, especially with such a small sample size. Further, some criteria may be more important than others. Weighting might have been appropriate, but might have been also pure speculation. Because our aim was to compare 2 techniques for preoperative planning, no intraoperative images were made. Because they are used clinically, their inclusion might have given a more accurate reflection of their utility, possibly improving the outcome grading for the radiographic group; however, we demonstrated that in the CT group no radiographs are necessary during surgery to determine screw alignment and length.

Our study did not evaluate true clinical internal fixation of a sagittal distal phalanx fracture because a fracture was not created, and clinically, fractures may not be truly sagittal and the glide hole may not stop right at the fracture plane. Further it did not assess compression of the fracture gap, especially at the articular surface, which is critical for prognosis. Horses with distal phalanx fractures are often very lame, which might affect clinical CT scan acquisition. In our experience, lame horses with distal phalanx fractures tolerate scanning of the affected limb well,[15] but this should be investigated in a higher number of clinical cases with high-grade lameness. Although it has been stated that inserting 2 screws to achieve increased compression and rotational stability is advisable,[14] we did not assess the feasibility and accuracy of these techniques for insertion of 2 screws.

Our results showed that the pQCT scanner is likely a feasible alternative to fluoroscopy or CAS.[14] With the CT technique, none of the screws penetrated the joint, the semilunar canal, or the solar surface. They were inserted in a central position in the distal phalanx (mean score for outcome 4 = 1.6). One screw was too short; this was identified during surgery but the screw was not changed because of the study criteria. The conventional technique was also efficient in identifying the position and direction of the screw, and none of the 10 screws penetrated the joint, the semilunar canal, or the solar surface. However, the surgical technique used to determine screw length in the radiography group was clearly less accurate than measurement with CT. This might be because of difficulty in localizing the far cortex with the depth gauge. In most specimens, it was difficult to accurately identify the interface between the far bone surface and the lamellae. Therefore, there was a risk that the average length was inaccurate. We have experienced this clinically and it can be considered one of the difficulties of this surgical procedure. The calculated length might be used when measurement is felt inaccurate, but this would require further experimentation. The high number (6) of screws that were too short with the radiography technique was also because for the purpose of this study, screws that were loose or of inappropriate length were not replaced by longer ones, as it would occur clinically. Further, no control radiographs were taken that could have been useful where screw length deviated obviously from the optimal length.

Radiography was as accurate as CT in identifying the axis of the screw in a plane parallel to the solar surface. This was probably because of the correction of hoof balance before radiographs were taken. CT was more accurate in identifying the ideal frontal plane, probably because the 3D software available with this CT system enabled observation of the distal phalanx in all directions.

Honnas and Trotter[9] and Bertone[3] reported use of control radiography during surgery to guide screw placement; however, they did not report the number of radiographs which are usually needed. Clinical experience suggests numerous radiographs are often necessary. This increases radiation exposure and lengthens surgical time. Fluoroscopy is another option that was not tested. As a consequence of preoperative planning, surgical times were relatively short in this study, with the CT technique being the quickest. Instead of trephining a 10 mm,[3] 11 mm,[11] or 14 mm[7] hole through the hoof wall at the beginning of surgery, we created a 4.5 mm trephine hole with a 4.5 mm drill bit. It is only at the end of the procedure that a final 8 mm (CT group) or 14 mm (R group) gap in the hoof wall was created. We think that we gain in accuracy, for clamp placement and subsequent drilling of the glide hole into the bone, by starting with an initial 4.5 mm trephine hole in the hoof wall. It is also possible that the smaller (8 mm) final hole that is necessary with the CT technique (where we only need to account for the diameter of the screw head and countersink), in comparison with the larger (10 or 14 mm) hole required in the radiography technique (where we also have to account for the passage of the depth gauge), might facilitate postoperative healing. However, to our knowledge, there are no studies that show that smaller drill holes improve postoperative healing and this would require further research.

In their study, Andritsky et al[7] reported that screw length had to be adjusted with both conventional and CAS techniques because of countersinking and deviation of the drill hole from the planned trajectory. Use of the clamp and initial drilling of a 4.5 mm trephine hole might ensure better control of the drilling direction. Countersinking should ideally be kept to a minimum because the distal phalanx is soft cancellous bone that might collapse under the screw head.[3] In our study, countersinking was minimal and it maybe that other surgeons would recommend more aggressive countersinking for the head of the screw.

We have shown that standing CT can be used to accurately determine anatomic landmarks for insertion of screws in lag fashion in sagittal fractures of the distal phalanx. This cadaveric study also indicates that with the CT technique we describe, surgical time is shorter, which might also reduce the risk of general anesthesia. Studies in live horses are needed to substantiate these observations.

REFERENCES

1. Dyson SJ: Fractures of the distal phalanx, in Ross MW, Dyson SJ (eds): Diagnosis and Management of Lameness in the Horse. Philadelphia, PA, Saunders, 2003, pp 318–321
2. Yovich JV, Hilbert BJ, Mc Gill CA: Fractures of the distal phalanx in horses. Aust Vet J 59:180–182, 1982
3. Bertone AL: Fractures of the distal phalanx, in Nixon AJ (ed): Equine Fracture Repair. Philadelphia, PA, Saunders, 1996, pp 146–152
4. Honnas CM, O'Brien TR, Lindford RL: Distal phalanx fractures in horses: a survey of 274 horses with radiographic assessment of healing in 36 horses. Vet Radiol 29:98–107, 1988
5. Scott EA, Mc Dole M, Shires MH: A review of third phalanx fractures in the horse: sixty five cases. J Am Vet Med Assoc 199:595–597, 1979
6. Gabel AA, Bukowiecki CF: Fractures of the phalanges. Vet Clin North Am 5:233–260, 1983
7. Andritzky J, Rossol M, Lischer C, et al: Comparison of computer-assisted surgery with conventional technique for the treatment of axial distal phalanx fractures in horses: an in vitro study. Vet Surg 34:120–127, 2005
8. Yovich JV, Stashak TS, DeBowes RM, et al: Fractures of the distal phalanx of the forelimb in eight foals. J Am Vet Med Assoc 189:550–554, 1986
9. Honnas C, Trotter G: Articular fractures of the distal phalanx, in White N, Moore J (eds): Current Techniques in Equine Surgery and Lameness (ed 2). Philadelphia, PA, Saunders, 1998, pp 389–397
10. Rick MC: Navicular bone fractures, in White NA, Moore JN (eds): Current Practice of Equine Surgery. Philadelphia, PA, Lippincott, 1990, pp 602–605
11. Honnas CM: Surgical treatment of selected musculoskeletal disorders of the forelimb, in Auer JA (ed): Equine Surgery. Philadelphia, PA, Saunders, 1992, pp 985–1054
12. Fackelman CE: Screw fixation of sagittal fractures of the third phalanx in horses. Vet Med Small Anim Clin 69:1317–1324, 1974
13. Young DR, Kobluk CN: Diseases of bone, in Kobluk CN, Ames TR, Geor IJ (eds): The horse: Diseases and Clinical Management. Philadelphia, PA, Saunders, 1995, pp 785–786
14. Auer JA, Lischer C, Andritzky-Waas J, et al: Comparison of computer assisted and conventional repair of distal phalanx and distal sesamoid fractures: early results. *Proceedings, 15th Annual Scientific Meeting ECVS,* June 2006, Sevilla, Spain, 2006, pp 231–233
15. Desbrosse FG, Vandeweerd JMEF, Perrin RAR, et al: A technique for computed tomography (CT) of the foot in the standing horse. Equine Vet Educ 20:93–98, 2008
16. Field A: Effect sizes, in Field A (ed): Discovering Statistics Using SPSS. London, Sage Publications, 2005, pp 28–52