Computed Tomography or Magnetic Resonance Imaging-Assisted Partial Hoof Wall Resection for Keratoma Removal

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Objectives: To (1) describe the computed tomography (CT) and magnetic resonance imaging (MRI) appearance of keratomas; (2) describe a CT- or MRI-assisted partial hoof wall resection technique for removal of keratomas; and (3) evaluate the morbidity and postoperative outcome of these horses.

Study Design: Case series.

Animals: Horses (n = 10) with keratoma.

Methods: Data retrieved from medical records included signalment, lameness duration and grade, physical and diagnostic evaluation findings, CT and MRI technique and findings, surgical details, histopathologic diagnosis, postoperative treatment, and complications experienced. Long-term outcome was obtained by telephone interviews of owners.

Results: Complications including excessive granulation tissue formation and infection were seen in 2 horses (20%). No keratoma recurrence occurred. Follow-up information was available for 8 horses; 7 were sound and had resumed work. Mean time until they became sound was 2.7 months, and mean time until work resumed was 3.6 months.

Conclusions: CT and MRI can be used to accurately identify the location of keratomas. Postoperative complications may be decreased by creating smaller hoof wall defects, filling the defects with antimicrobial-impregnated polymethylmethacrylate, and placing a shoe early in the postoperative period.

Keratomas are a rare cause of lameness in horses; however, they do occur frequently enough to be one of the more common indications for surgery of the equine foot.1–4 They are aberrant, hyperplastic keratin masses that typically originate from the stratum germinativum of the coronary band, or less commonly from other areas of the hoof wall or sole.1–4 Their cause is unknown—they have been hypothesized to be caused by either a preceding traumatic event or subsolar infection, although these are not always consistent historical findings. The treatment of choice is surgical debridement through either a complete or partial hoof wall resection.1–3

Complications after surgery include excess granulation tissue formation, hoof crack formation, hoof wall instability, infection, and keratoma recurrence.2,4 In a recent report, 50% of horses that had keratoma removal experienced one of these complications; however, significantly fewer horses that had partial hoof wall resection developed complications when compared with those that had complete hoof wall resection (25% versus 71%, respectively).4 Horses with a partial hoof wall resection were able to return to use quicker than those with complete resections (7 versus 10 months, respectively). Others have experienced similar results; therefore, the current treatment of choice is keratoma removal through partial hoof wall resection to limit postoperative morbidity and allow for a quicker return to use.4,5

To perform a partial hoof wall resection, the exact location and extent of the keratoma must be identified preoperatively, typically by identifying a characteristic radiolucent defect in the distal phalanx on radiographs. However, radiography is not the ideal imaging modality for identification of keratomas and studies evaluating keratomas often include cases in which no radiographic abnormalities were found.2–4 Although radiographs may show a radiolucent defect in the distal phalanx resulting from pressure resorption induced by the overlying mass, the keratoma itself cannot be identified with this modality. Therefore, other imaging modalities would potentially be useful for determining the exact location and dimensions of the keratoma, thus limiting the size of the hoof wall resection needed while still ensuring that all of the abnormal tissue was removed.

Computed tomography (CT) and magnetic resonance imaging (MRI) have distinct advantages over radiography in terms of providing diagnostic information and aiding in surgical planning because of the highly detailed
cross-sectional and 3-dimensional reconstructed images that they provide. CT and MRI have been used to investigate various conditions of the equine foot but we are unaware of reports where either modality has been used to guide the surgical treatment of keratomas. Our objectives were: (1) to describe the CT and MRI appearance of equine keratomas; (2) to describe a CT- or MRI-assisted partial hoof wall resection technique for removal of keratomas; and (3) to evaluate the morbidity and postoperative outcome of horses treated in this manner. Our hypotheses were: (1) CT and MRI can accurately identify the exact location of keratomas and (2) a CT- or MRI-assisted partial hoof wall resection for keratoma removal will allow for a smaller hoof wall defect to be created, therefore potentially decreasing postoperative morbidity and allowing for a quicker return to work compared with results using conventional surgical treatment.

MATERIALS AND METHODS

All horses that had CT- or MRI-assisted partial hoof wall resection for keratoma removal were included (August 2006–April 2009). Medical records were reviewed and the following data was retrieved: signalment, history of subsolar abscess in or traumatic injury to the affected foot, affected limb, lameness grade (1–5), duration of lameness, physical examination findings of the affected foot, evidence of subsolar abscess at presentation, response to perineural or intraarticular analgesia, radiographic abnormalities found, the results of any other imaging modalities performed (ultrasonography or nuclear scintigraphy), and surgeon. Data obtained from surgical and anesthesia records included: duration of CT or MRI, duration of surgery, size of the partial hoof wall resection (length and width), medications administered peri- or intraoperatively (antimicrobials, nonsteroidal antiinflammatory drugs [NSAIDs] or intravenous regional limb perfusions [IV RLPs]), use of intraoperative perineural analgesia, substances placed in the hoof wall defect intraoperatively and type of shoe or bandage placed at the time of surgery. Postoperative information obtained included: number of days treated with antimicrobials, NSAIDs, and/or IV RLPs, day shoe was placed (if not performed at surgery), type of shoe placed, days hospitalized, complications encountered, and histopathology results.

Radiographic Examination

Five standard radiographic views were obtained in all horses (lateromedial, dorsopalmar/plantar, dorso 60° proximo-palmaro/plantarodistal oblique, dorso 45° latero 60° proximo-palmaro/plantaromediodistal oblique, and dorso 45° medio 60° proximo-palmaro/plantarolateral oblique). In select horses, additional views were obtained at the request of the surgeon (palmaroproximal-palmarodistal oblique, dorsomedial palmaro/plantarolateral oblique, or dorsolateral palmaro/plantaromedial oblique views).

CT or MRI Examination

The choice of CT or MRI examination was based on surgeon preference and the availability of the imaging modality. The size of the keratoma (length \(\times\) width [cm]) was measured on either the CT or MRI images.

CT Protocol

An 8-slice mobile CT scanner (EQUS I, Universal Medical Systems Inc., Solon, OH) was used to image the area from the foot to the pastern. Images were first obtained in the transverse plane (contiguous axial slices with a slice thickness of 1.25 mm obtained at 120 kVp and 4 mA) and this data was later reformatted using computerized software (DICOM 3.0, DICOM, Rosslyn, VA) to create 3-dimensional reconstructions of the affected area. Additional evaluations were performed using radiopaque paste (E-Z-Paste, Barium Sulfate Esophageal Cream, 60% w/w, E-Z-EM Canada Inc., Westbury, NY) as a marker to designate the location for the partial hoof wall resection. Markers were initially placed at the site of the hoof wall defect or bulge, or in the area thought to be overlying the keratoma by the clinician after viewing the radiographs and initial CT images. The markers were subsequently adjusted if indicated to accurately outline the keratoma based on the images acquired with the markers in place.

MRI Protocol

A low field magnet (0.25 T Vet MR Grande, Universal Medical Systems Inc.) was used to image the area from the foot to the pastern. In the early cases, an initial scan using a high resolution, gradient echo pulse sequence was obtained in the transverse plane with a 0.6 mm \(\times\) 1.2 mm \(\times\) 4.0 mm voxel (950 TR, 26 TE). In the later cases, an initial scan using a spin echo sequence was obtained in the transverse plane with a 0.6 mm \(\times\) 1.2 mm \(\times\) 3.0 mm voxel (760 TR, 16 TE). Subsequent scans were then performed using a paste with a high signal intensity (E-Z-Paste, Barium Sulfate Esophageal Cream, 60% w/w, E-Z-EM Canada Inc.) as a marker to designate the location for the partial hoof wall resection. Marker placement was selected as described above for the CT evaluations.

Surgical Procedure

Horses were anesthetized and positioned in lateral recumbency with the affected leg uppermost. General anesthesia was maintained with isoflurane in 100% oxygen through a semiclosed circle system. After CT or MRI evaluation, the proposed landmarks for the partial hoof wall resection were marked on the hoof by using a Dremel rotary tool with a cutting attachment (Dremel 4000 High Performance Rotary Tool, Dremel, Racine, WI) to score the hoof wall or by drawing on the hoof wall with a permanent marker. The foot was then trimmed, rasped and aseptically prepared and draped. In all horses except 1, perineural analgesia was performed at the level of the proximal sesamoid bones.
A pneumatic tourniquet was placed above the fetlock. A Dremel rotary tool with various high speed cutter attachments (Dremel High Speed Cutters [114, 117, 124, and 144], Dremel, Racine, WI) was used to remove the hoof wall in the area of the proposed resection. Once the hoof wall resection was complete, all abnormal tissue was removed with various bone curettes and rongeurs and samples were submitted for histopathologic evaluation. The hoof wall defect was filled in most cases with a collagen sponge (Ultrafoam Collagen Sponge, Davol Inc., Warwick, RI) soaked in amikacin (1.25–2.0 g) placed directly over the exposed portion of the 3rd phalanx. Enough soaked collagen sponge was placed to fill the void under the hoof wall up to the level of the deep side of the hoof wall. Polymethylmethacrylate ([PMMA] 20 g; Simplex-P®, Howmedica Osteonics, Rutherford, NJ) impregnated with amikacin (1.25–2.0 g) was then used to fill in the hoof wall defect. Cyanoacrylate (Vetbond™ Tissue Adhesive, 3M™, St. Paul, MN) further sealed the junction between the hoof wall and the PMMA plug. A foot bandage, with or without a glue-on horse shoe with a carbon fiber patch positioned over the PMMA plug, or a foot cast was placed before recovery from anesthesia. In select horses, IV RLP was performed under anesthesia using 2.0–2.5 g amikacin diluted to a total volume of 30–60 mL with 0.9% saline solution and infused over ~5 minutes through a palmar/plantar digital vein with a 25 g butterfly catheter (Terumo Medical Company, Elkton, MD). The pneumatic tourniquet was maintained on the limb for 20 minutes after the amikacin solution was injected and then deflated. Horses were treated perioperatively with various antimicrobials for 2–21 days depending on the surgeon’s preference. In select horses IV RLPs were continued for 1–3 days postoperatively.14 All horses were administered phenylbutazone (4.4 mg/kg IV) preoperatively and were maintained on phenylbutazone (2.2 mg/kg orally twice daily) postoperatively for 8–14 days.

Outcome
Postoperative complications encountered while the horse was hospitalized or as reported by the owner once the horse was discharged from the hospital were recorded. Long-term outcome was assessed using a telephone survey—owners were asked for the following information: horse’s use, time to return to work (months), time until sound (months), current level of soundness, postoperative complications, degree of satisfaction with the outcome of the surgery, and whether they would elect to have the procedure performed again.

RESULTS
Ten horses met the inclusion criteria. There were 6 Thoroughbreds and 1 of each of the following breeds: Quarter Horse, Paint, Arabian, and Spotted Saddle Horse. Mean age was 11.7 years (range, 5–21 years; median, 10.5 years). There were 8 geldings and 2 mares. Six horses were used for trail riding, 3 for hunter/jumper or dressage, and 1 was a steeplechaser. The right front foot was affected in 5 horses, the left front foot in 4, and the left hind foot in 1. Mean duration of lameness was 176 days (range, 2–365 days; median, 155 days) and mean lameness grade was 2.7 (range, 1–4; median, 3). Five horses had a history of subsolar abscesses; 4 were chronic and recurrent and 1 was acute. These horses all had a subsolar abscess present in the affected foot at the time of admission. In 8 horses, additional hoof abnormalities were present at admission and included: a solar defect at the white line with drainage in 5 horses, a bulge or separation at the white line without drainage in 2, a coronary band swelling in 2, a hoof wall crack in 1, and a coronary band defect in 1. One horse had a history of a traumatic injury to the affected foot. Four horses did not have any history of subsolar abscess or traumatic injury of the affected foot.

Diagnostic analgesia was performed in 7 horses. In 4 horses, the lameness was completely abolished after palmar digital perineural analgesia performed just proximal to the collateral cartilages of the foot. In the other 3 horses, the lameness was moderately improved after this block and was completely abolished with additional palmar digital perineural analgesia performed at the level of the base of the proximal sesamoid bones in 1 horse and intraarticular distal interphalangeal analgesia in 1 horse. The remaining horse did not improve with additional intraarticular distal interphalangeal analgesia. Nuclear scintigraphy was performed in 2 horses and revealed moderate, focal increased radiopharmaceutical uptake in the distal phalanx in the area of the keratoma in each horse (1 in the medial wing and 1 in the lateral solar surface). The specific area of increased radiopharmaceutical uptake in both cases was best localized using the solar views.

Radiographic evaluation revealed a radiolucent, circular to semicircular defect in the affected 3rd phalanx in all horses (Fig 1). The location of the radiolucent defect in the 3rd phalanx was: dorsolateral solar surface (5), dorsomedial solar surface (5), dorsomedial solar surface (2), palmarodistal lateral surface (1), palmarodistal medial surface (1), and the dorsoproximal lateral surface (1).

CT Findings
CT examination was performed in 3 horses. In all horses the keratoma could be easily and reliably imaged (Fig 2). The keratoma appeared as a mass originating from the hoof wall, with a similar radiopacity as the hoof wall, and protruding into the underlying distal phalanx. In each case, the mass was circular and the area of the distal phalanx beneath the mass contained a semicircular defect consistent with resorption of the bone in that area. The full extent of the mass could be appreciated by scrolling through sequential cross-sectional images or by viewing the 3-dimensional reconstructed images (Fig 3).

MRI Findings
MRI examination was performed in 7 horses. In all horses, the keratoma could be easily and reliably imaged (Fig 4);
however, the imaging characteristics of keratomas were more similar to keratinized hoof wall than the underlying lamina. Because of inadequate water content, the hoof capsule is not evident in MR images and the attachment of the keratoma to the hoof capsule cannot be reliably identified. The keratoma instead appeared as either a hypointense signal void (Fig 4A) or as a heterogeneous intermediate intensity mass (Fig 4B) protruding into the underlying distal phalanx, creating a semicircular defect consistent with bony resorption. The full extent of the mass could be appreciated by scrolling through sequential MR images in various planes.

Mean keratoma size (as measured on CT or MR images) was 1.6 × 3.3 cm (width × length; median 1.5 × 3.1 cm; range for width 1.1–2.7 cm; range for length 1.9–5.5 cm).

Surgical Findings

Mean surgery time was 49 minutes (median, 45 minutes; range, 33–70 minutes), mean time required to perform a MRI examination was 28 minutes (median, 27 minutes; range, 11–43 minutes), and mean time required to perform a CT examination was 15 minutes (median, 17 minutes; range, 9–20 minutes). The mean size of the partial hoof wall resection performed was 2.6 × 3.9 cm (width x length; median 2.5 × 3.8 cm; range for width 2.0–3.0 cm; range for length 3.0–5.5 cm). In all horses, the mass grossly appeared to be confined to the area outlined in the imaging study. In 8 horses, the defect in the hoof wall was filled at the time of surgery with an amikacin-impregnated collagen sponge and PMMA as described. In the other 2 horses, the defect was left open and covered with a sterile gauze sponge. Three horses had a shoe placed at the time of surgery; 3 horses had a shoe placed the day after surgery; and 3 horses had shoes placed at 2, 5, and 30 days after surgery. One horse did not have a shoe placed after surgery. IV RLPs were performed at the time of surgery in 3 horses.

Outcome

Two horses had postoperative complications. Horse 1 developed excessive granulation tissue formation at the site of the hoof wall resection 8 weeks after surgery. This horse had significant subsole abscission and coronary band separation present at the time of surgery. Because of the extent of the preexisting infection this horse received the most extensive course of antimicrobial therapy; the surgical defect was filled with an amikacin-impregnated collagen sponge and amikacin-impregnated PMMA as described. IV RLPs were performed intraoperatively and then daily for 3 days after surgery, and the horse received procaine penicillin G (22,000 U/kg intramuscularly twice daily).
starting the morning of surgery for 3 doses and was then maintained on trimethoprim sulfamethoxazole (25 mg/kg orally twice daily) for 21 days. The infection resolved with this treatment. The granulation tissue was treated with standing surgical debridement of the tissue; the debrided tissue was submitted for histopathology to rule out keratoma recurrence and was confirmed to be granulation tissue. The granulation tissue did not recur after this treatment.

Horse 10 had moderate hemorrhage during surgery and continued to have hemorrhagic discharge around the PMMA plug for 3 days postoperatively. This horse subsequently developed a localized infection at the surgical site. The infection resolved after medical treatment with trimethoprim sulfamethoxazole (25 mg/kg orally twice daily for 2 weeks), removal of the PMMA plug and debridement of infected tissue, and lavage of the surgical site with sterile saline solution for 10 days. It was hypothesized that the location of the keratoma in this horse—the palmar aspect of the distal phalanx, near the foramen through which the lateral palmar artery travels—likely contributed to the hemorrhage and thus the subsequent infection.

Although not categorized as a complication in this or other reports, 5 horses were markedly (i.e. toe-touching to non-weight-bearing) lame in the affected limb postoperatively which resolved without further treatment within 12–24 hours. Four of these 5 horses did have perineural analgesia of the palmar digital nerves performed at the level of the proximal sesamoid bones at the time of surgery. Horses were hospitalized for a mean of 6 days (median, 5.5 days; range, 3–11 days). Histopathology of tissue debrided at surgery was characterized in 9 horses as a large focus of keratin with sheets and small whorls of orthokeratotic keratinocytes consistent with a diagnosis of keratoma.

Information on long-term follow-up was available for 8 horses a mean of 16 months after surgery (median, 14 months; range, 7–27 months). Seven horses were sound
and had returned to their previous athletic use at the time of the survey. Horse 8 was lame at the time of the survey. This horse had surgery 7 months before the survey; the surgical site had healed well and the horse had not experienced any complications related to the surgery. This horse had preexisting lameness because of osteoarthritis before surgery and the owner felt that the horse’s lameness was attributable to the osteoarthritis and not a result of the surgery; however, no lameness exam or diagnostic nerve blocks had been performed to confirm this assumption.

The mean time until the other 7 horses became sound after surgery was 2.7 months (median, 2 months; range, 1–8 months). The mean time until those 7 horses returned to work was 3.6 months (median, 3 months; range, 1–8 months). No horses had keratoma recurrence. All 8 owners who responded to the survey were satisfied with the outcome of the surgery and would elect to have the procedure performed again.

**DISCUSSION**

Our results confirm the hypothesis that CT or MRI can be used to accurately identify the exact location of keratomas. This allows for a smaller hoof wall resection to be made, while still ensuring that the keratoma is removed in its entirety. Horses in this report experienced decreased postoperative morbidity rates (20%) compared with those in other reports treated by traditional surgical techniques.\(^2\)\(^3\)\(^4\)\(^5\)

Two retrospective studies have evaluated postoperative morbidity in horses after keratoma removal; in 1 report, 1 out of 7 horses had keratoma recurrence that required a 2nd surgical debridement and another horse was persistently lame after surgery.\(^3\)\(^6\) In a more recent study with a larger number of horses (n = 26), 50% (13/26) of horses experienced a postoperative complication, although the complication rate was significantly higher for horses that had a complete hoof wall resection performed (71% [10/14]) than those that had a partial hoof wall resection performed (25% [3/12]).\(^4\) The most common complication seen in that study was excess granulation tissue formation (8 horses) followed by keratoma recurrence (3 horses), hoof crack formation (2 horses), and surgical site infection (1 horse).

In our study, 1 horse developed excess granulation tissue at the surgical site 8 weeks after surgery which resolved with standing surgical debridement of the tissue. This horse had severe subsolar infection present at the time of the original surgery and this was thought to have contributed to the formation of the excess granulation tissue. A 2nd horse developed a surgical site infection after surgery; this horse experienced substantial intra- and postoperative hemorrhage that may have predisposed it to this complication. The infection resolved with medical therapy. Bacterial culture and antimicrobial susceptibility testing was not performed in these cases, but could have been considered to better direct antimicrobial therapy. However, in cases where infection was present either pre- or postoperatively, broad-spectrum antimicrobial coverage was provided systemically with trimethoprim sulfamethoxazole. Local antimicrobial therapy with amikacin was chosen since most bacteria responsible for orthopedic infections in our hospital are susceptible to amikacin. Infection resolved in both horses.

Horses were able to return to work more quickly than those previously reported. In those studies, horses were able to return to work at 6–12 months after surgery.\(^3\)\(^6\) Horses undergoing partial hoof wall resections returned to work more quickly than those undergoing complete hoof wall resections (mean of 7 versus 10 months, respectively).\(^1\)\(^4\) Our horses returned to work a mean of 3.6 months after surgery and reportedly were sound by a mean of 2.7 months. The long-term outcome of these horses also compares favorably with previous reports, with 7 out of 8 horses becoming sound and returning to their previous use, compared with 25 of 26 in another report.\(^4\) The horse that was not sound at the time of follow-up was not reevaluated by a veterinarian, but the owner felt that the horse was lame because of other preexisting orthopedic issues.

The reason for the decreased postoperative morbidity rates and quicker return to work seen in these horses is likely multifactorial. CT or MRI assistance allows for a smaller hoof wall resection to be made, while still ensuring that all of the abnormal tissue is removed. Previous reports have found that postoperative complications are decreased when a partial hoof wall resection is used, allowing for hoof wall stability to be maintained.\(^2\)\(^4\) However, a disadvantage of performing a partial hoof wall resection using only radiographic guidance is the potential for keratoma recurrence if all of the abnormal tissue is not removed at the time of surgery. In 1 study, keratoma recurrence occurred in 3 of 26 horses, 2 of which had a partial hoof wall resection performed.\(^4\) As these cases were treated using radiographic guidance, the full extent of the keratoma was likely not evident, which could explain the recurrence. None of our horses that had long-term follow-up have experienced keratoma recurrence.

Other factors that likely played a role in the outcome of the horses in our report are the methods used to seal the hoof wall defect at the time of surgery and the fact that a shoe was placed earlier than in previous reports. In 8 of 10 horses, the hoof wall defect was filled intraoperatively with an amikacin-impregnated collagen sponge and an amikacin-impregnated PMMA plug. This served dual purposes of helping maintain hoof wall stability while also providing prophylactic local antimicrobial therapy. Additionally, most of the horses (8/10) were placed in a glue-on shoe with a carbon fiber patch over the plug either at the time of surgery or within 5 days after surgery. Although filling the defect with PMMA has been reported, previous reports do not describe doing so at the time of surgery, but instead used it as a delayed treatment.\(^2\)\(^4\)\(^15\) In our opinion filling the defect at the time of surgery with an antimicrobial-impregnated PMMA plug and then placing the type of shoe described either intraoperatively or early in the postoperative period allows these horses to return to work more quickly because hoof wall stability is maintained and because infection is decreased by the use of local antimicrobial therapy.
Both CT and MRI proved to be valuable diagnostic imaging modalities for guiding the surgical approach in these horses. The choice of imaging modality was largely reliant on what was available at the time of surgery. Our initial horses had MRI because CT was not available. Once CT became available it was used in the subsequent horses. For the purposes of guiding the surgical excision, either modality was acceptable; the keratoma could be easily and reliably imaged and surgical landmarks established with either technique. In our hospital, MRI took longer to perform than CT (mean 28 versus 15 minutes, respectively); however, the overall range of times for both imaging modalities represents the learning curve associated with using a new technique and with both modalities, the time required to provide an image needed for surgical guidance became progressively shorter. The times required for the most recent cases performed with each technique were 9 minutes for CT and 11 minutes for MRI. Our preference is to use CT for keratomas, because overall it is quicker, requires less technical skill to acquire diagnostic images, and repeat imaging once the markers are in place is quickly and easily performed.

We concluded that CT and MRI can be used to accurately identify the exact location of keratomas to guide surgical treatment. By performing CT- or MRI-assisted partial hoof wall resection to remove keratomas, the smallest possible hoof wall resection can be made while still ensuring complete resection of the keratoma. The combination of creating a smaller hoof wall defect, filling the defect with an antimicrobial-impregnated collagen sponge and a PMMA plug at the time of surgery, and placing a glue-on shoe with a carbon fiber patch over the plug intraoperatively or in the early postoperative period may decrease postoperative morbidity and allow horses to return to work quicker after CT- or MRI-assisted partial hoof wall resection than has been reported with conventional surgical techniques.

REFERENCES