Hoof lacing in zoo ungulates—indications, technical descriptions, and outcomes in a giant eland (Taurotragus derbianus), African Cape buffalo (Syncerus caffer), and greater one-horned rhinoceros (Rhinoceros unicornis)

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CASE SERIES

Hoof lacing in zoo ungulates—indications, technical descriptions, and outcomes in a giant eland (*Taurotragus derbianus*), African Cape buffalo (*Syncerus caffer*), and greater one-horned rhinoceros (*Rhinoceros unicornis*)

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Abstract: Hoof lacing was performed for treatment of vertical hoof wall cracks in a giant eland (*Taurotragus derbianus*), African Cape buffalo (*Syncerus caffer*), and a greater one-horned rhinoceros (*Rhinoceros unicornis*) to provide stability after observing progression toward, or involvement of, the hoof wall over the coronary band. A total of five hoof lacing procedures were performed, with a single greater one-horned rhinoceros undergoing three procedures on two different hooves. Although this technique is frequently performed in domestic equids, the utility in nondomestic ungulates has not been evaluated. A technical description is provided to serve as a resource for zoo professionals to consider when vertical hoof cracks are encountered that warrant advanced intervention. Hoof lacing facilitates normal hoof growth by using stainless steel sutures to reduce the margins of the vertical hoof crack and provide hoof wall stability, which may be further reinforced with the addition of an overlying Kevlar® patch. In each case, the laced vertical hoof crack migrated toward the solar surface with new hoof growth, and the cracked hoof wall resolved. Although the cause of vertical hoof wall cracks may be multifactorial, and it is essential to implement mitigation strategies as part of a holistic treatment plan, hoof lacing should be considered in zoo ungulates when indicated if the expertise and equipment are available.

INTRODUCTION

Lameness is a disruption of the expected ambulation cycle and most often the result of pain or mechanical impairment. In addition to orthopedic, soft tissue, or neurologic dysfunction as causes of lameness, disease of the hoof is an important cause of morbidity in zoo ungulates. There is a growing body of literature, largely on the basis of comparison models to the domestic horse (*Equus caballus*) and cow (*Bos taurus*), describing anatomy, lameness diagnosis, preventive management, causes, hoof trimming programs, and treatment therapies in zoo ungulates, suggesting hoof health is an important aspect of the care provided to zoologic animals.[4,15]

One cause of lameness in ungulates is vertical cracks or fissures. Vertical hoof wall cracks have the potential to result in lameness if they involve the sensitive corium, the coronary band, or result in instability of the hoof capsule. Lameness-causing vertical hoof cracks may be full thickness through the hoof wall, extend toward the hoof wall overlying the coronary band, or be associated with secondary infection. Vertical hoof wall cracks are common in pastured beef cows and less frequently documented in horses.[5–7,9,12] The prevalence of vertical hoof wall cracks in zoo ungulates has not been reported, but anecdotally, they have been observed in numerous species with progression, manifestation of clinical signs, and lack of resolution tending to be more common in larger species.[15]

Hoof lacing is one technique to consider for vertical hoof wall cracks and has been described in horses to resolve lameness, prevent progression of cracking, and promote healing. The primary objective of hoof lacing is to provide mechanical stability to the hoof wall to prevent crack progression and create an environment that facilitates normal hoof growth at the coronary band by placing sutures across the vertical crack. Many of the techniques used in equine vertical hoof crack management can be applied to large zoo ungulates, and the authors describe the outcomes in a giant eland (*Taurotragus derbianus*), African Cape buffalo (*Syncerus caffer*), and greater one-horned rhinoceros (*Rhinoceros unicornis*) that underwent hoof lacing for vertical hoof crack management.

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Figure 1. Vertical hoof cracks on a giant eland (*Taurotragus derbianus*) left forelimb medial claw (**A**), African Cape buffalo (*Syncerus caffer*) left forelimb medial claw (**B**), and greater one-horned rhinoceros (*Rhinoceros unicornis*) left forelimb digit three prior to undergoing a hoof lacing procedure (**C**) and 92 days after initial hoof lacing (**D**), as well as a vertical crack of the right forelimb digit during the latter procedure (**E**).

CASE REPORTS

Technical description

All hoof wall lacing procedures were performed using a similar technique to treat vertical cracks (Fig. 1). Each animal was anesthetized in a hospital, field, or boma setting, intubated, and placed in lateral recumbency on the contralateral side of the affected leg. A greater one-horned rhinoceros had a lacing procedure performed on both forelimb feet during a single anesthesia. The animal was maintained in left lateral recumbency for hoof lacing of the right and left forelimb digit three hooves, using pads at the level of the axilla and elbow to appropriately position the leg. Lateral, dorsopalmar, and oblique projection radiographs were obtained prior to hoof wall lacing.

The hoof wall was cleaned of debris using a towel and warm water. A high-speed rotary tool (Dremel, Robert Bosch Tool Corporation, Illinois, USA) with a rotary carving bit was used to explore the extent of the crack and clean debris and abnormal keratin. This created a clean fissure, allowed for more detailed evaluation of the crack depth, and improved assessment for potential lamellar tissue involvement deep in the crack. Sets of paired holes, approx. 1 cm apart, were marked on either side of the hoof wall crack using a permanent marker to approximate the location of holes that would be drilled. Holes were drilled using a 1.19-mm-diameter cobalt bit (3/64 inch) approx. 2 cm from the edge of the crack and to a depth of 1 cm with the holes exiting within the vertical hoof crack (Fig. 2). A stainless steel suture (10.16 cm in length × 1.2 mm in diameter; 18 ga.) with stainless steel backing plates (Sound Horse Hoof Crack Suture Kit, Sound Horse Technologies, Kentucky, USA) was placed through predrilled holes approx. every 0.5–1.0 cm, with a goal of placing sutures at the proximal and distal most extent of the crack. Sutures were advanced, so the free ends were in the hoof wall crack, and the backing plate was opposed to the hoof wall (Fig. 3). If the hoof wall was too thin to drill holes through the keratin wall toward the crack, a methacrylate hoof adhesive (Pro Fast Patch 420, Grand Circuit Products LLC, Kentucky, USA) was applied to either side of the vertical hoof crack to increase the surface area for

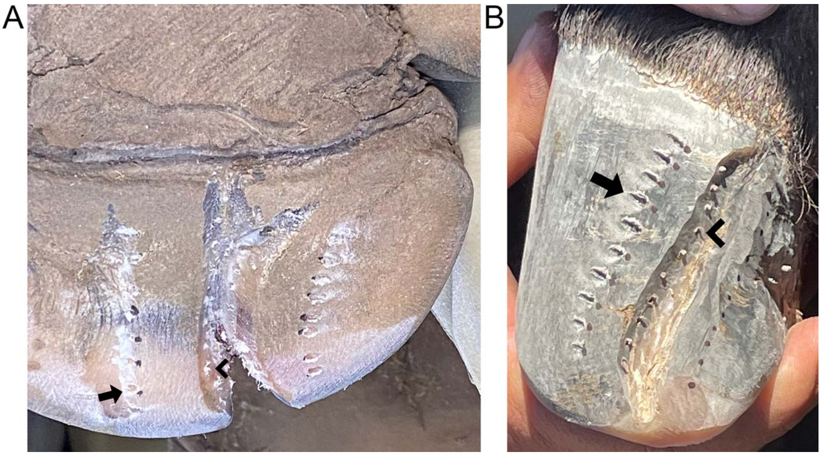

Figure 2. A hoof being prepared for stainless steel sutures placement to lace a vertical hoof crack of the left forelimb digit three in a greater one-horned rhinoceros (*Rhinoceros unicornis*) that extended to the palmar surface. (**A**) There are 8 holes on each side of the hoof crack on the palmar surface. The arrows denote an example of the holes on either side of the hoof crack that extend from approx. 2–3 cm lateral to the margins of the hoof crack toward the central aspect of the crack. The chevron denotes the drill hole exiting within the crack. (**B**) A similar example of the procedure is provided for an African Cape buffalo (*Syncerus caffer*) with 10 holes on either side of the vertical hoof crack on the medial claw of the left forelimb.

stainless steel suture placement. Once all sutures were placed, the free ends were twisted together which firmly seated the backing plates against the hoof wall and put tension on the vertical crack. The goal of twisting the sutures was to stabilize the vertical crack. In smaller species or narrow cracks, some crack reduction may be observed, but crack closure is not the intended goal. Excessive suture length was cut, and the remaining twisted wire was directed into the hoof crack (**Fig. 3**).

A two-part silicone-based putty material (sole support impression material for equine hooves; Soft, Equine Digital Support System Inc., Colorado, USA or Equiflex-Pak™, Sound Horse Technologies, Kentucky, USA) was impregnated with copper sulfate pentahydrate 100% (Allen's Blue Powder, Farrier Product Distribution,

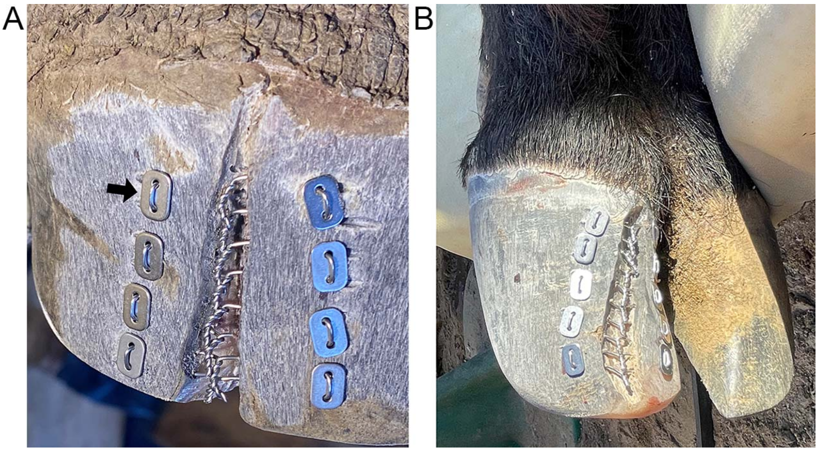

Figure 3. A vertical hoof wall crack in a greater one-horned rhinoceros (*Rhinoceros unicornis*) (**A**) with stainless steel sutures placed to stabilize the crack. The sutures are placed on both sides of the cracks and are opposed by twisting the free ends together. Twisting the sutures applies pressure to the end plates (arrow) providing slight reduction to the vertical hoof crack and stability to the hoof wall. A similar vertical hoof crack in African Cape buffalo (*Syncerus caffer*) (**B**) following stabilization using stainless steel sutures.

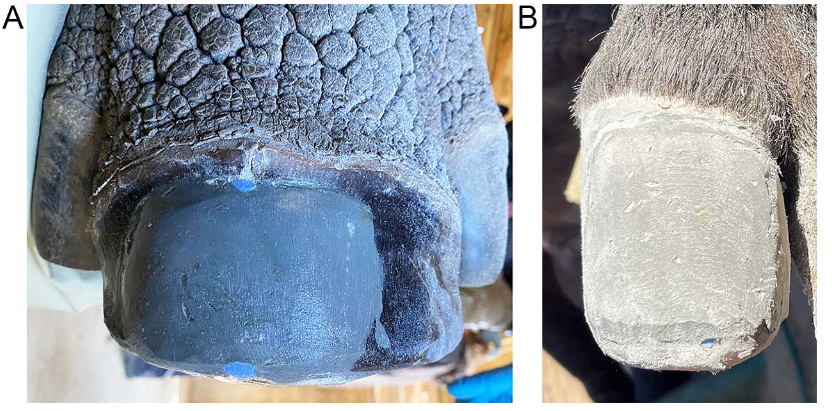

Figure 4. The hoof appearance following lacing and placement of a Kevlar patch in a greater one-horned rhinoceros (*Rhinoceros unicornis*) left forelimb digit three (**A**) and an African Cape buffalo (*Syncerus caffer*) left forelimb medial claw (**B**). Note the adhesive closely contouring to the hoof wall resulting in a smooth surface.

Kentucky, USA) and applied with digital pressure over the twisted stainless steel sutures in the vertical hoof crack. A Kevlar® and carbon fiber–braided tube patch (Cobrasox Hoof Repair Fabric, Sound Horse Technologies, Kentucky, USA) was cut to size to cover the entire length of the vertical hoof crack and extended approx. 2–3 cm beyond the lateral margins of the crack. The patch was secured over the crack using an adhesive (Equilox-1, Equilox International, Minnesota, USA). The hoof was temporarily wrapped in plastic to promote removal of air from the adhesive and allow for close contouring of the adhesive to the hoof wall. The adhesive was allowed to set for 10 minutes, and any prominent ridges were removed using gentle sanding to create a smooth surface (Fig. 4). For all cases, there were no movement restrictions implemented aside from those considered for anesthesia recovery. All animals resumed normal husbandry and activity in field habitats. When possible, weekly observations through visual inspections or photos were attempted, but debris covering the hooves often precluded detailed assessment. No attempts were made to remove the Kevlar patch or stainless steel sutures, and the sutures and patch detached as the hoof wall grew out and was appropriately worn. On rare occasions when minimal debris was covering the laced hooves during the hoof-wearing process, stainless steel sutures were visible for a short period of time before being separated from the hoof and becoming no longer visible. At no time was a loose or dangling stainless steel suture observed.

Giant eland

A 7.5-year-old, 530-kg male giant eland was anesthetized for evaluation of an abaxial hoof wall vertical crack on the left forelimb medial digit (Fig. 1A) and moderate lameness for 1 week. Prior to this, the animal had regular hoof trims to address hoof capsule distortions characterized by hoof wall toe overgrowth. The vertical hoof wall crack commenced approx. 3 mm distal to the coronary band and extended approx. 4 cm toward the sole wall junction. A hoof wall lacing procedure was performed under general anesthesia to stabilize the vertical hoof crack. Four stainless steel sutures were used to bridge the hoof wall crack. The animal was sound immediately after hoof trimming. The laced crack was monitored by visual inspections and photographs for 219 days, when a follow-up hoof trim was performed, which revealed no concerns and approx. 3 cm of growth between the previously laced crack and the coronary band. The approximate growth rate of the hoof was 0.41 cm/month, which is consistent with the hoof growth rate in most ungulates. The animal died from an unrelated cause 78 days after hoof trimming and 297 days after lacing. The animal was sound at the time of death, and measurements between the laced crack and coronary band were not recorded at necropsy.

African Cape buffalo

A 7.9-year-old, 700-kg male African Cape buffalo was anesthetized for evaluation of chronic, severe left forelimb lameness. Prior to hoof wall lacing, the animal was anesthetized multiple times for hoof trimming and radiographs, which revealed a vertical hoof crack of the dorsal aspect of the left forelimb medial claw that extended the entire length of the hoof wall from the palmar solar aspect to the coronary band (Fig. 1B). Radiographs revealed multifocal osteophytosis of all joints in this foot (fetlock, phalanx one [P1]–P2, and P2–P3). Minimal to no clinical response was noted after corrective hoof trimming, systemic mesenchymal stem cell treatment, administration of nonsteroidal anti-inflammatories, gabapentin, and boma rest on flat ground. The vertical hoof crack failed to improve, and a hoof wall lacing procedure was performed to stabilize the vertical hoof crack. Briefly, 10 stainless steel sutures were applied across the vertical crack (Fig. 3B). The animal was sound immediately following the procedure and was moved to a large and complex field habitat and bred numerous females without any signs of lameness. Close observation and photos of the hoof wall growth of this animal were not possible given the location and habitat environment. At 152 days following hoof wall lacing, the animal was immobilized to change habitats, and the adhesive covering the Kevlar patch was still in place but had migrated with new hoof capsule growth. The animal has been sound for over 2 years following hoof wall lacing and has bred multiple cows with no observations of vertical hoof crack recurrence.

Greater one-horned rhinoceros

A 9.5-year-old, 1,900-kg female greater one-horned rhinoceros was anesthetized for evaluation of a progressive left forelimb lameness. Over 3 weeks, a vertical hoof wall crack progressed from the toe of the left forelimb digit three toward the coronary band and the palmar surface of the foot toward the foot pad (Fig. 1C). Retrospective review of opportunistic photographs revealed that a subtle, thin vertical crack was present approx. 3 months prior to presentation. The vertical crack on the dorsal aspect of the toe was approx. 4 cm deep at the toe and tapered to 1 cm deep toward the coronary band. Similarly, the palmar crack of the sole extended from the toe caudally and tapered to 1 cm deep near the heel. Orthogonal view radiographs revealed a complete, minimally displaced P3 fracture of the left forelimb digit three approx. 1.2 cm medial to the vertical hoof wall crack. A hoof wall lacing procedure was performed using 16 stainless steel sutures, with 8 sutures placed in the dorsal aspect of the hoof wall (Fig. 3A) and 8 sutures placed in the palmar surface. The animal was sound after lacing and was evaluated weekly with photos.

Ten days after lacing the left forelimb digit three vertical crack, a right forelimb digit three vertical crack that started at the toe and progressed until approx. 2 cm distal to the coronary band and 3 cm on the solar aspect was observed with no associated lameness (Fig. 1E). The crack was superficial with a 1- to 2-mm-wide gap along most of the hoof wall and slight widening toward the toe and solar surface. This right forelimb digit three vertical crack remained static, with no progression or lameness over the next several weeks. One month following the left forelimb hoof wall lacing procedure, the Kevlar patch covering the sutures on the palmar surface was worn and the intact stainless steel sutures were visible. Also, a protuberance was noted at the left forelimb digit three coronary band, immediately proximal to the previously laced crack. Five weeks after the lacing procedure, a new vertical crack was noted extending from the previously laced vertical crack toward the coronary band. At 9 weeks following the initial lacing procedure, the left forelimb vertical wall crack on digit three continued to progress toward the coronary band with lateral deviation. At 10.5 weeks, a complete horn avulsion was documented while sustaining subjectively minor trauma. On the basis of visual inspection, there was no evidence of frontal bone fracture or nasoconchal sinus involvement, and the site healed without complication.

Thirteen weeks after the initial left forelimb digit three hoof wall lacing procedure, the animal was anesthetized for lacing procedures of the progressive left forelimb digit three vertical crack (Fig. 1D) and the right forelimb digit three crack (Fig. 1E). Both cracks were relatively shallow with the right forelimb crack measuring 0.5 cm deep and the left forelimb crack measuring 0.25 cm deep. Due to the relatively shallow depth of the cracks, buildup was required to support the stainless steel sutures, and acrylic glue was placed parallel to the cracks to create an additional area of purchase for the stainless steel sutures and backing plates to engage. A total of 12 sutures were used on the right forelimb digit three crack, and 6 sutures were used on the left forelimb digit three crack. Repeat orthogonal view radiographs of the left forelimb demonstrated significant reduction of the previously documented radiolucent fracture line consistent with appropriate healing but minimal callus formation. Appropriate fracture healing may be partially attributed to vertical crack stabilization. Right forelimb digit three radiographs revealed no skeletal concerns. No lameness was appreciated following the procedure. Six weeks following the second lacing procedure, an estimated 2 cm of normal hoof wall was documented proximal to the laced vertical wall cracks, representing approx. 8 mm of new hoof growth over this period. At 11.5 weeks following hoof wall lacing, the Kevlar patch and stainless steel sutures were no longer present on either the right or left forelimb digit three hoof wall. The animal remained sound with no vertical hoof cracking at 24 weeks after follow-up hoof wall lacing. Serum vitamin A status of this animal was unknown prior to anesthesia for initial left forelimb digit three hoof lacing. On the basis of serum vitamin A levels obtained at the time of immobilizations, this animal was suspected to have low serum vitamin A (initial sampling = 20–30 μg/L and subsequent level =14 μg/L), and oral supplementation at 250 IU (vitamin A as palmitate 500 IU/ml oil suspension, Wedgewood Pharmacy, New Jersey, USA) was administered once daily, top-dressed on food. Repeat serum vitamin A quantification has not been performed.

DISCUSSION

Hoof lacing using stainless steel wire and Kevlar patching for treatment of vertical hoof wall cracks in a giant eland, Cape buffalo, and greater one-horned rhinoceros resulted in resolution of hoof crack wall progression and near immediate return to sound ambulation. This technique has been described in domestic equids, but its use in zoo ungulates has not been previously described in detail. Vertical cracks can be frustrating to manage given the potential for progression, lack of resolution, and morbidity in the form of lameness. Although management of vertical hoof cracks may require a multifaceted approach to mitigate potential contributing causes, hoof lacing should be considered a treatment option, and this case series suggests application potential in a wide variety of zoo ungulates, including rhinoceros. Given success in these species, translation to other zoo ungulates such as other rhinoceros species or giraffes may be considered.

Vertical hoof cracks are common in beef cattle, with one study reporting sand cracks in 22.7% of cows on pasture in Alberta.[7] The forelimbs (86%) are more commonly affected in cattle, which is suspected to be due to increased weight loading compared with the rearlimbs.[14] Vertical wall cracks on the lateral claw of the forelimbs are more common than those on the medial claw (80.6% vs 19.4%, respectively).[7] When stratified by age and weight, older and heavier cows had a higher prevalence of vertical cracks with 47.9% of cows older than 5 years having vertical cracks.[5] In horses, the prevalence of vertical wall hoof cracks appears less common, with 1.64% of Thoroughbred racehorses at one track having documented quarter cracks.[12] The horses in this study returned to racing on average 50 days after first treatment and continued to race after treatment, suggesting that with adequate treatment, resolution is possible. The prevalence of vertical hoof wall cracks in zoo ungulates is unknown, but subjectively, they seem more common on the forelimbs of larger species, which may suggest that body weight is associated with vertical hoof cracks, similar to beef cattle.

Other than hoof imbalances frequently associated with capsule distortions, the underlying causes of vertical cracks are often unknown. In beef cattle, a correlation with increased age, weight, and body condition has been documented.[5] Pathogenesis was explored in various breeds of beef cows by evaluating claw volume, sole surface area, toe length, and hoof horn hydration, with a positive correlation identified between claw volume and vertical fissures.[2,3] In horses, hoof wall cracks can be caused by coronet injuries, poor-quality hoof walls due to genetics, nutrition, or environmental causes, white line disease, inappropriate farrier practices, or hoof capsule distortion, with hoof capsule distortions being considered the most common cause.[8,13]

Multifactorial causes likely contribute to the development of vertical hoof wall cracks in zoo ungulates with hoof capsule distortions hypothesized as likely a primary contributing factor. Increased activity, such as reproductive behaviors (pursuit, mounting, and breeding) in the giant eland and Cape buffalo, is considered a predisposing factor because both individuals were herd sires. In addition, the Cape buffalo had radiographic evidence of osteophytosis, which likely resulted in abnormal weight bearing and hoof capsule distortion, and the eland required repeated trims to address toe wall overgrowth. Vitamin A is required in the differentiation of keratinized cells and the greater one-horned rhinoceros had a low serum concentration.[11] Vitamin A deficiency can lead to hard keratin being brittle and unevenly laid down.[8] The animal in this case series had both forelimbs affected with vertical wall cracks despite no significant hoof distortions, avulsed its horn unexpectedly, and showed no evidence of crack recurrence once oral vitamin A supplementation was initiated, which may support underlying hypovitaminosis A contributing to the clinical horn and hoof concerns. In addition to hoof lacing, each of the animals had hoof trims performed to address excessive length and hoof capsule distortions. Similar to domestic ungulates, it is important to consider nutritional, hoof trimming, stall resting, or other supplemental interventions that will support healthy hoof growth if lacing is attempted in zoo ungulates.

In zoo ungulates, treatment success will be limited, and cracks are likely to recur if the initiating cause of the crack cannot be identified and mitigated. Therefore, prioritization of prevention needs to be considered before treatment options are explored. An important treatment decision is determining when intervention is needed, because not all vertical hoof wall cracks require intervention. In vitro studies of the domestic equid hoof demonstrate that the normal hoof has inherent properties to mitigate vertical fissures and protect inner sensitive structures, including tubule arrangement and density within the stratum medium to resist compressive mechanical forces.[10] In many cases, the vertical cracks are superficial, the horse is sound, or the location of the crack on the hoof wall is minimally concerning for progression. Assessment of zoo ungulates can present additional challenges compared with domestic animals, because intervention may be limited without sedation or anesthesia. Closer assessment and preparation of a therapeutic plan should be considered in zoo ungulates with vertical hoof cracks that cause lameness, overlay the coronary band with associated swelling, extend the entire hoof wall length from the sole to the coronary band, demonstrate no evidence of normal hoof growth at the coronary band, are full thickness with evidence of bleeding, or demonstrate instability with possible independent movement between either side of the crack at any phase of the gait.

In the domestic horse, treatment options include one or more of the following: corrective trimming with or without shoeing, minimizing activity, plating with a composite of polymethacrylate adhesive, plating with a metal plate and screws, or lacing with stainless steel sutures.[13] Treatment decisions depend on personal preferences, technical expertise, equipment availability and comfort, and lesion appearance and location. The decision to lace with stainless steel sutures and patch with Kevlar was selected in these cases because the size of the animal warranted a robust system that would engage the hoof wall on both sides of the crack to promote stabilization, the hoof wall was determined to likely be thick enough to place stainless steel sutures without encountering underlying sensitive tissue, and the farrier preferred this method.

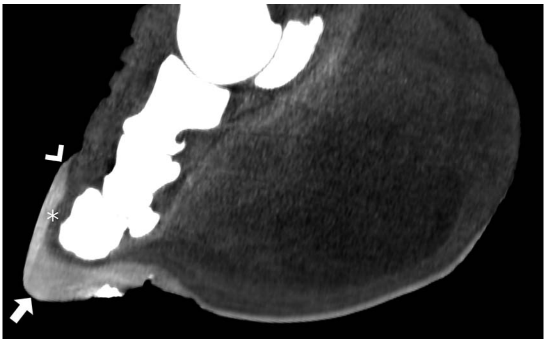

Figure 5. A sagittal computed tomography image in a soft-tissue window demonstrating the tapered appearance of the hoof wall in a greater one-horned rhinoceros (*Rhinoceros unicornis*). The hoof wall is hyperattenuating to the underlying sensitive laminae (asterisk) and thickest at the toe (arrow), tapering significantly over the region of the coronary band (chevron).

Similar to that of the horse, the greater one-horned rhinoceros hoof wall is thickest at the toe and tapers proximally near the coronary band. Prior to the procedure, a review of postmortem computed tomography images of greater one-horned rhinoceros forelimbs provided a resource to plan and anticipate the limitations associated with lacing immediately over the coronary band (Fig. 5). The tapering of the hoof wall over the coronary band limited the depth of the sutures and ultimately the ability to place sutures in close proximity to the coronary band without encountering sensitive tissues. The necessity of a second procedure to augment the first in this individual was likely due to the inability to completely lace the crack immediately over the coronary band and potential keratinization deficits associated with hypovitaminosis A, which was first documented at the initial examination and supplemented prior to the second procedure. The right forelimb digit three crack was relatively shallow and in close proximity to the coronary band. By building up the hoof wall in this region using an acrylic adhesive, stainless steel sutures could be placed across the crack without encountering sensitive tissue. In a similar fashion, prior to the hoof wall lacing procedure on the Cape buffalo and giant eland, lateral radiographs were performed to evaluate hoof wall thickness, and a domestic cow reference was consulted to aid in procedure planning.[1] Radiographs are recommended prior to hoof wall lacing, especially in zoo ungulates, to more completely evaluate the hoof anatomy and wall thickness.

CONCLUSION

Vertical hoof wall cracks, specifically complete hoof wall cracks that extend from the sole wall junction of the hoof to the coronary band at the toe, can be challenging to treat and often result in morbidity in the form of persistent lameness and discomfort. Hoof wall lacing has been used in a giant eland, African Cape buffalo, and greater one-horned rhinoceros to prevent progression of vertical hoof wall cracking and provide mechanical stability to allow for normal growth at the coronary band and subsequent hoof wall. Hoof wall lacing is an advanced hoof care technique and can be attempted by experienced and trained personnel when indicated in zoo ungulates.

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