46

Footcare for Zoo Ungulates (Zoo Hoofstock Trim Program)

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Abstract

Zoo hoofstock species can benefit from routine hoof trims, as is a standard of care in domestic species like horses and cattle. While there are limited studies describing foot shape and foot health of free-ranging ungulates, differences in diet, exercise, substrate, and other factors may contribute to hoof overgrowth and associated lameness for zoo hoofstock species. To manage and appropriately trim hoof overgrowth requires an understanding of how the hoof wall, heel, and sole can grow and distort, and should include trimming from the solar surface. Over time, hoof overgrowth and secondary hoof capsule distortions may lead to ligament injuries, osteoarthritis, or other pathologies. Restoring normal weight-bearing with hoof trims can help minimize disease progression. With some causes of foot pain including solar abscesses, laminitis, or pedal fractures, shoes or boots can be applied after hoof overgrowth has been removed. Proactive interventions that include hoof trims and medical management may be needed to successfully manage hoof cracks or infections. This chapter highlights techniques that can help manage some common foot diseases of zoo ungulates.

Introduction

Foot disease in ungulates is often associated with limping, increased morbidity, and sometimes with early mortality.[1–5] While management of foot diseases in domesticated species like horses,[6] cows,[7,8] goats,[9] and pigs,[5] and in megaherbivores such as elephants,[10,11] have been relatively well described, there are fewer reports of foot conditions and effective management for other ungulates. This chapter describes techniques to evaluate foot health and to manage some types of foot disease in nondomestic artiodactyls (even-toed ungulates) and perissodactyls (odd-toed ungulates). Regular routine hoof trimming for zoo ungulates could help prevent many causes of lameness and would benefit health and welfare.

Foot Function and Anatomy

The foot is a dynamic structure designed to protect from injury and infection and also functions to absorb shock and biomechanical loads.[1,12] While equids bear weight on a single digit for each foot, other ungulates have multiple digits which alter how weight is distributed. For example, when comparing the foot of a horse and elk (*Cervus canadensis*), the alignment of bones around the distal interphalangeal joint (DIJ or coffin joint) differs dramatically, indicating more differences to the functionality of the foot than simply having more digits (Fig. 46.1).

The hoof capsule includes all external structures of the foot. It consists of the hoof wall, sole, frog, hoof wall terminations, and heel bulbs (Fig. 46.2).[12] The hoof wall is made of keratin, is continuous with the epidermis, and grows primarily from the coronary band (corium) toward the ground.[12] The hoof wall has three layers: the stratum externa (periople), stratum media, and stratum internum.[12] The stratum internum comprises the epidermal laminae (insensitive laminae) that interlock the hoof with deeper laminar structures.[12] The solar surface consists of the hoof wall, the sole, and the frog. The bars are the site of termination of the hoof wall. The caudal surface of the foot is the heel bulb, which is not a weight-bearing structure. With abnormal weight distribution over time, the hoof capsule will develop an irregular shape.

Within the hoof capsule are both soft tissue and bony structures. Deep to the hoof wall is the connective tissue corium, or dermis, that includes the dermal laminae (sensitive laminae) that connects the hoof wall to the distal phalanx (Fig. 46.3C).[12] The bones within the hoof capsule are the distal phalanx (third phalanx or coffin bone), a portion of the middle phalanx (second phalanx or short pastern), and the distal sesamoid (navicular) bones.[12] With these bones are associated cartilage, bursa, the DIJ, tendons of insertion of the common digital extensor, and deep digital flexor muscles, blood vessels, and nerves.[12] Collateral

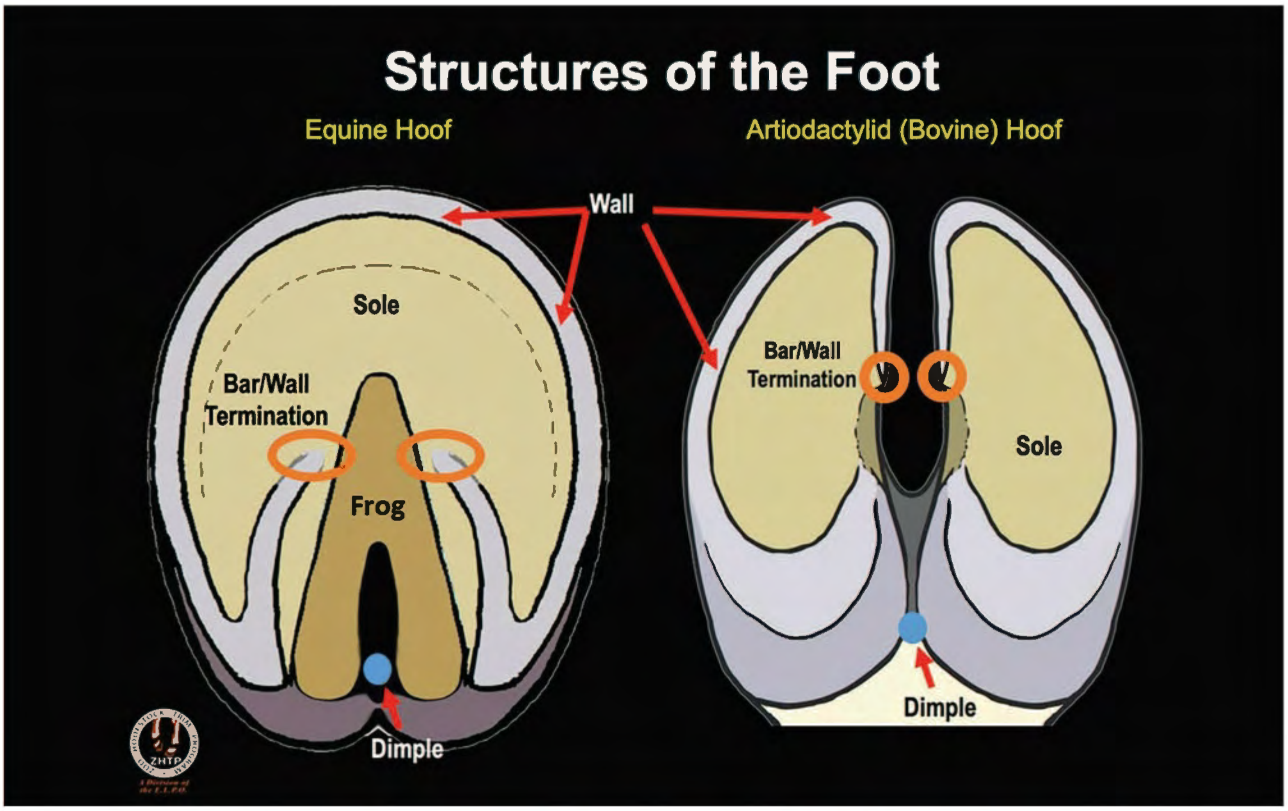
• **Figure 46.1** Bones of the foot and distal interphalangeal (coffin) joint positioning in equid (on *left*) vs artiodactylids (elk *[Cervus canadensis]* foot, on *right*). This photo includes the 1st (P1), 2nd (P2), and 3rd (P3) phalangeal bones, but not the distal sesamoid bones. Based on the alignment of the phalanges, there is more weight bearing of the equine foot directly into P3 compared with the artiodactyl foot that is oriented more caudally in the distal interphalangeal joint.

ligaments provide stability both medially and laterally.[12] Key structures in the hoof include the digital cushion, the deep digital flexor tendon, the impar ligament (connects distal sesamoid bones to the distal phalanx), and the distal sesamoidean ligament.[12]

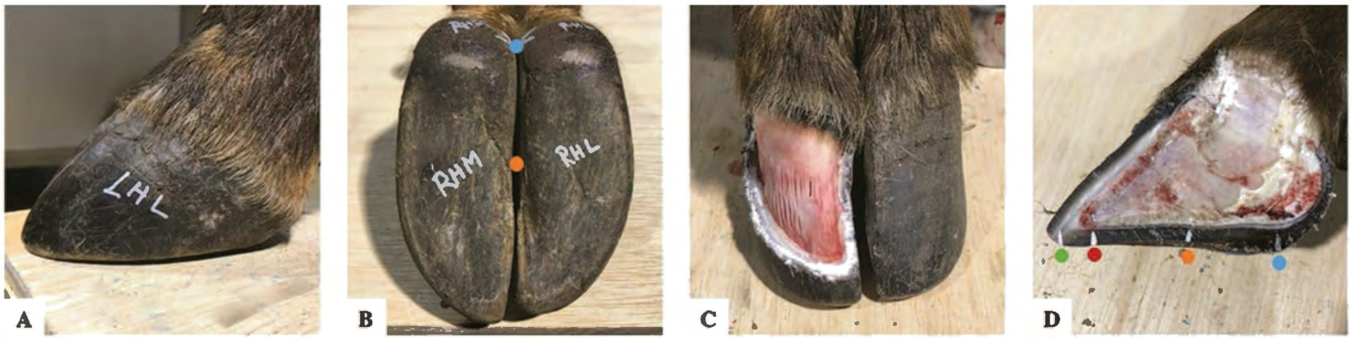
Wild Foot Studies

The feet of some free-ranging ungulates have been studied to help identify differences between self-maintained feet and the feet of animals in human care (see Fig. 46.3). Feral horses self-maintain a longer hoof wall toe tip in softer/sandy substrates,[13] a shorter overall hoof wall in harder substrates,[13]and may have advanced foot disease depending on environment and nutritional factors.[14,15] Free-ranging Nubian giraffe have marked differences in foot shape, pedal angles, and foot pathologies compared with some zoo-housed giraffe.[16] While these studies may inform hoof trimming practices in zoos, they are not a "gold standard" because of the many other factors such as substrate,[17,18] conformation,[3] nutrition,[3,19,20] infection,[21] injury,[22] and exercise[23] that may impact foot health.

A study of hoof angles for multiple African ungulates reported a very large variation in hoof angles.[24] For example, of 18 impala *(Aepyceros melampus)*, the front foot hoof angle ranged from 35 to 55 degrees, and for 59 Burchell's zebra *(Equus quagga burchellii)*, the front foot hoof angle ranged from 50 to 63 degrees.[24] In comparison, the domestic horse front foot has a markedly smaller normal foot angle of 45 to 50 degrees.[25] This wide range of individual variation suggests that until more information is available, the hoof should be trimmed based on the individual pattern of hoof overgrowth and not to a specific foot angle.



• **Figure 46.2** Palmar anatomy of the foot for both a horse and cow. Where the bar/hoof wall terminates by the frog (equine) or by the interdigital space (artiodactyl) may serve as a static reference despite hoof distortions. The distance between the dimple (*blue* circle) and bar/hoof wall termination (*red* circle), when doubled, may help locate the tip of the distal phalanx bone.



• **Figure 46.3** Wild elk *(Cervus canadensis)* foot that self-maintained with no hoof overgrowth or distortions. (A) The coronary band is relatively straight on the lateral view. (B) The solar view of the foot has good symmetry, there is no debris impacted into the sole, and there is no obvious overgrowth of hoof wall, heel, or sole. The dimple of the foot is located near the heel surface at the hairline (blue circle). The termination of the hoof wall is located by the interdigital space (*orange* circle). (C) View of normal laminar structures of the foot, once a portion of the hoof wall has been removed. (D) Cross-sectional view of the foot, demonstrating the sole of the foot is relatively thin and runs parallel to the palmar surface of the distal phalanx bone. The distance between the dimple (*blue* circle) and hoof wall termination (*red* circle), when doubled, may help locate the tip of the distal phalanx bone (*red* circle). The toe tip of the hoof should be trimmed (*green* circle) distal to the tip of the bone to avoid injury to bone or vasculature.

Preventive Management

The mantra "no hoof, no horse" emphasizes the importance of maintaining foot health. For this reason, it is a general standard of care to provide hoof trims for horses every 6 to 8 weeks, more often in cases of foot disease or lameness. While domestic cattle usually do not have the same performance or longevity expectations as horses, the impacts of foot disease on production and welfare make lameness prevention and management a priority. Notably, dairy cows have a lower prevalence of lameness when hoof trims are on a routine schedule of once or twice annually compared with when they are trimmed only when hoof overgrowth or lameness is observed.[26]

Many nondomestic ungulates have a relatively long lifespan in zoos but are not on a frequent schedule for routine hoof trims. In human care, these animals often have different exercise, substrates, and diets compared to wild counterparts. The hoof will then overgrow and develop secondary hoof capsule distortions. For example, for one large herd of zoo giraffe *(Giraffa camelopardalis reticulata)* not on a routine schedule of hoof trims, this resulted in hoof overgrowth and secondary lameness with pathologies such as osteoarthritis by 7 years old and sometimes distal phalanx fractures by 10 years old.[2] This suggests that waiting for hoof overgrowth to be severe or for an animal to have clinical lameness is not sufficient to maintain foot health. When these kinds of chronic degenerative changes occur in relatively young hoofstock, sometimes only palliative care is then possible.

Safe, regular access to maintain foot health requires behavioral, physical, or chemical restraint. Proactively training hoofstock to voluntarily participate in foot assessments and treatments may help with diagnosing foot diseases early.[27] If the solar surface of the foot cannot be assessed with voluntary participation, slow-motion videography may be used to collect images for assessment. When repeat treatments are required, animals trained to voluntarily participate often will receive more frequent care than if only physical or chemical restraint is possible. This may impact long-term prognosis.

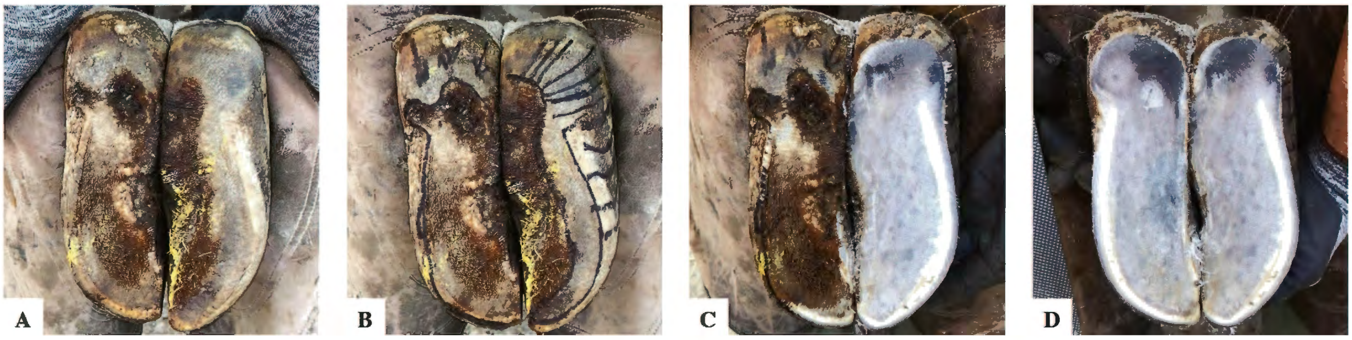
Identifying and Correcting Foot Disease

While describing management of all foot diseases in ungulates is beyond the scope of this chapter, the foundation of foot care is learning to identify how disease changes foot shape and function. Assessing for hoof capsule symmetry is essential and should be done both with the foot standing and from the underside of the foot (Fig. 46.4). When the hoof wall, heel, and sole overgrow, the tissue folds in on itself and creates hoof capsule asymmetries (Fig. 46.5).

Restoring hoof capsule symmetry helps normalize foot function and weight bearing.[28] The hoof trim may alter depth of the sole, angle of the dorsal hoof wall, and mediolateral symmetry.[29] While many hoof trim techniques may be adapted from horses, evaluating the growth pattern of the individual foot is important since reference angles are not available for most species.

Foot health management requires preparation and planning. Often, medical management may begin before the trim, with the additional benefit that this may improve patient comfort and thus cooperation during hoof trim sessions. Whether the hoof trim is to be done with training or restraint, the team should first review and discuss safety protocols. The area where the trim will take place should be clean and well lit, and hoof trim equipment should be clean and sharp. A warm water foot soak before the hoof trim may make trimming easier if the sole or hoof is very hard. Hoof trims should be performed by an individual or team with specific hoof trimming training and

• **Figure 46.4** When the foot is only assessed in a weight-bearing position, foot disease may be easily missed. (A) Front foot of a giraffe *(Giraffa camelopardalis reticulata)* that has no obvious hoof overgrowth but has mild curving to the coronary band which may be an indicator of early hoof capsule changes. (B) On exam of the solar surface, both the sole and heel are overgrown. (C) After removing the overgrowth, a heel bruise (O) and an abscess (Δ) are identified.



• **Figure 46.5** Assessing overgrowth and trimming the hoof in artiodactyls. (A) In this giraffe *(Giraffa camelopardalis reticulata)* foot, there is overgrowth of the hoof wall, sole, and heel. (B) On the sole near the interdigital space are hairlike projections that are found when the papilla of the sole overgrow and separate. The hand-drawn black lines on the hoof wall and heel show the direction of overgrowth and how the tissue folds and distorts. As the heel grows forward and the wall folds towards the midline of the foot, the wall bends which creates asymmetry. If this overgrowth is not addressed from the sole surface, the toe tips may overlap (screwclaw). (C) After trimming to the sole plane which removes the papilla overgrowth, the heel and wall are now back to their normal position at the periphery of the foot. (D) As the overgrowth is removed, the normal orientation of the toe is restored.

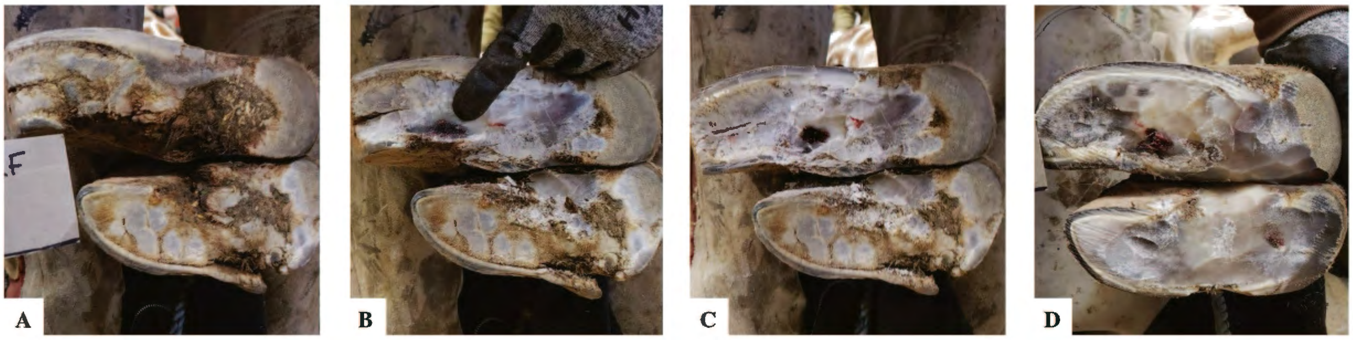
experience, and continuing education on techniques is highly recommended.

The sole is a key landmark to guide hoof trims (Fig. 46.6). The functional sole runs parallel to the distal phalanx bone and has a waxy appearance. Sole overgrowth should be removed to the level of this waxy plane and may then be used to help guide trimming of the hoof wall and heel. In artiodactyls especially, sole and heel overgrowth create a characteristic bulging appearance of the collapsed heel (Fig. 46.7) which may damage structures within the hoof capsule.

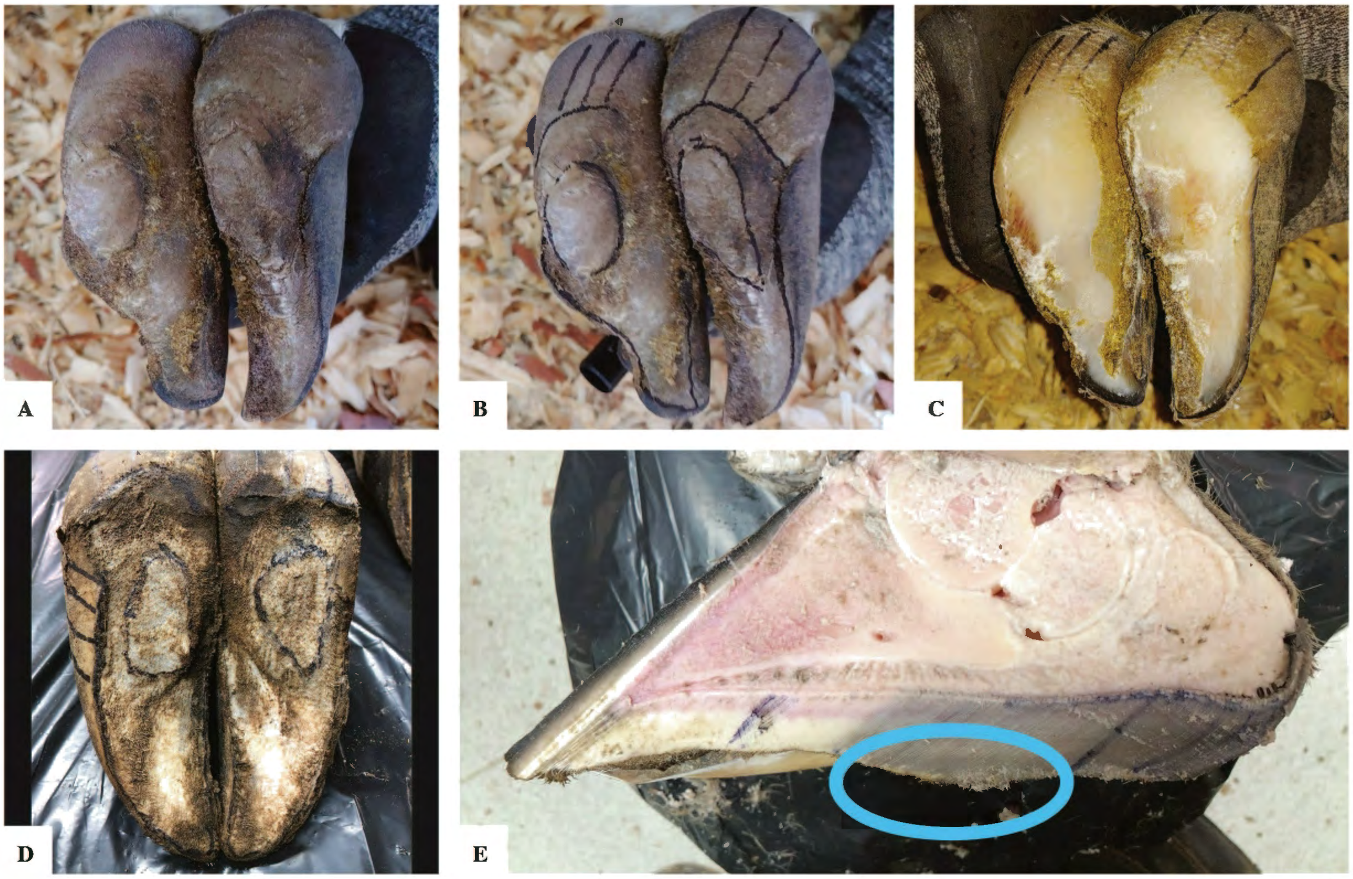
Sole overgrowth may often be associated with bruises, abscesses, and foreign bodies. Many sole abscesses may be associated with color changes in the sole surface, odor, and sometimes purulent discharge, although subsolar abscesses may be more difficult to diagnose (Fig. 46.8). In the author's experience (Foxworth), exotic equids are especially susceptible to White Line Disease (WLD or seedy toe) where the sole-hoof wall junction separates and develops secondary infection (Fig. 46.9). This is especially common in animals housed in wet, humid climates. WLD disease has also been well described in horses, cattle, and sheep.[22,30,31] Left untreated, WLD may progress to damage within the hoof capsule, including necrosis of the tip of the distal phalanx.

Excessive sole wear (or over-trimming) may be associated with bruises, erosions, and ulcers (Fig. 46.10). In these cases especially, it is important to evaluate substrate, conformation, and for stereotypic behaviors. Some cases may require husbandry changes, bandaging, or glue-on shoes (Fig. 46.11).

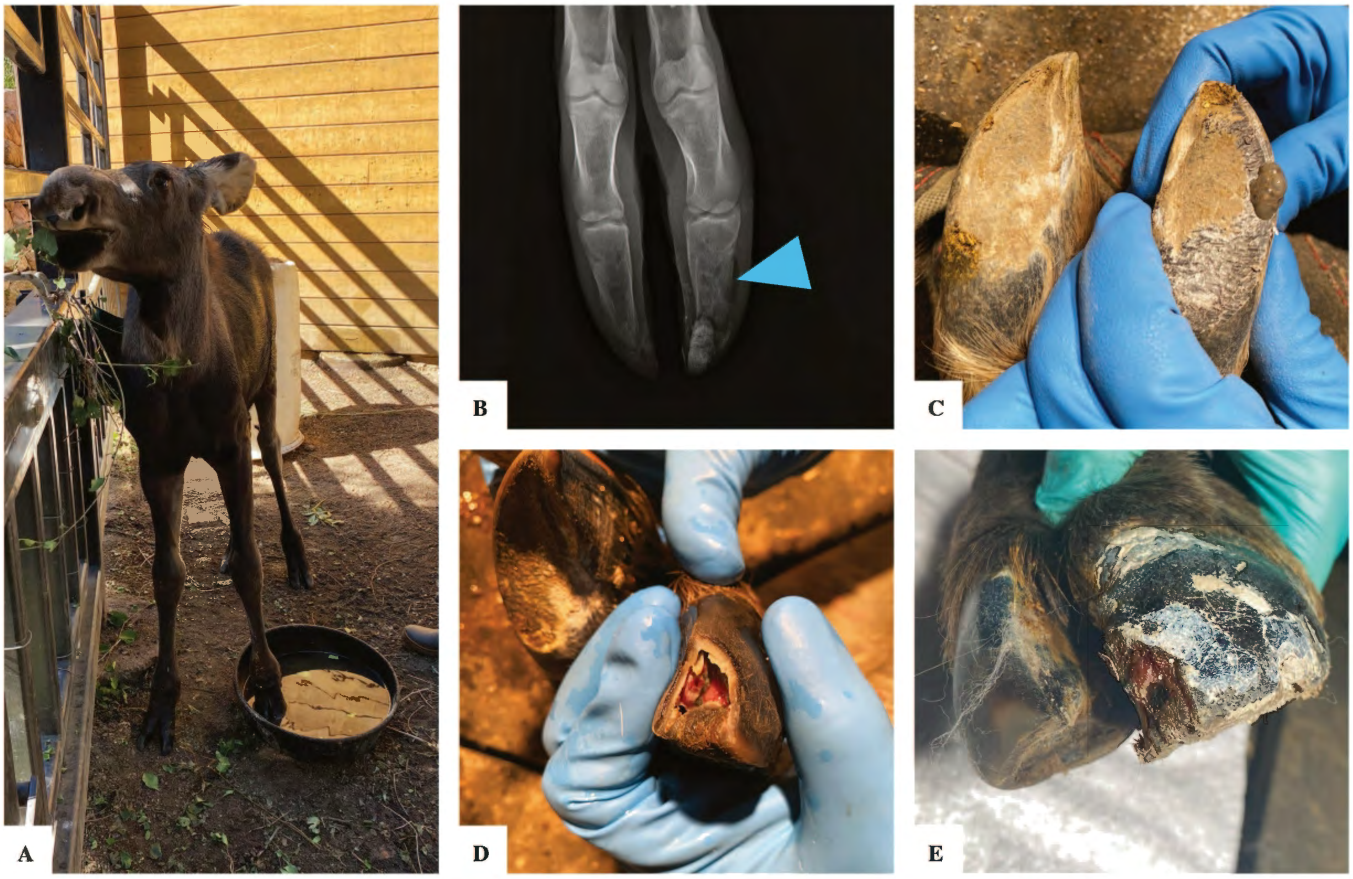
Hoof wall diseases may include overgrowth with secondary asymmetry, vertical or horizontal hoof cracks (Fig. 46.12), and may indicate nutritional disease such as laminitis. When hoof cracks are vertical, this is often the result of chronic abnormal weight-bearing of the foot. In comparison, horizontal hoof cracks are often associated with abscesses. Both cases require a thorough investigation into underlying causes for appropriate medical



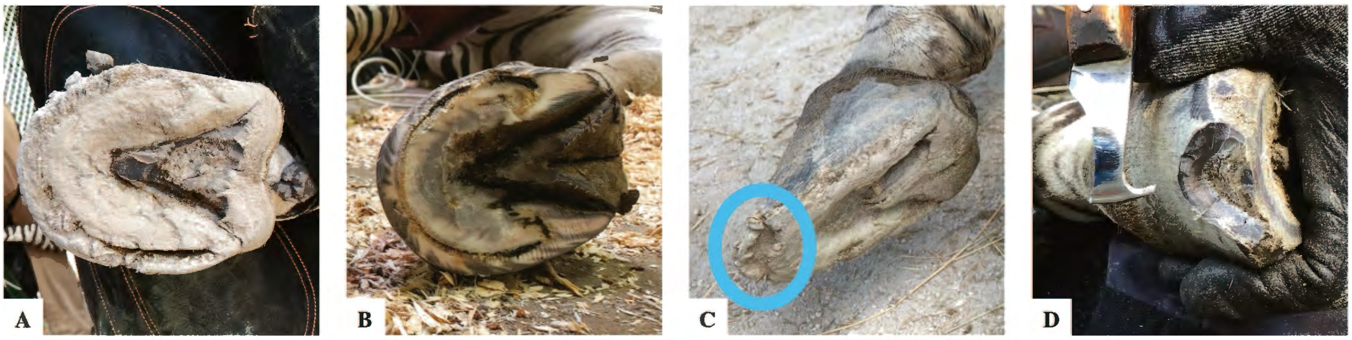
• **Figure 46.6** The sole plane is still used as a guide to trim the hoof when marked hoof overgrowth, hoof capsule distortions, and abscess are present. Overgrown sole tissue may have an irregular surface, while the underlying healthy sole plane will have a waxy appearance and runs parallel to the palmar/plantar aspect of the distal phalanx bone. (A) A giraffe (*Giraffa* sp.) hoof with marked overgrowth and distortions is trimmed by exfoliating to (B) the functional sole and a sole abscess is now visible. (C and D) Additional exfoliating of the sole in parallel to healthy sole removes much of the abscess and helps trim the foot to restore symmetry. The abscess is then packed with wound dressing and a protective shoe may be applied.



• **Figure 46.7** Sole and heel overgrowth in artiodactyls often creates a characteristic bulge of the sole near the heel. (A and B) An addax (*Addax* sp.) with early overgrowth of the sole and a collapsed heel. (C) After a hoof trim, note that the overgrowth has been removed, but there are discolored bruised areas on the sole that correspond to where some of that overgrowth had been. After removing the heel overgrowth, weight bearing of the foot is markedly more caudal than before the trim. (D) A giraffe (*Giraffa* sp.) with a similar pattern of sole and heel overgrowth. (E) On cross section, the sole near the heel is bulging, which would cause chronic pressure and compression to the adjacent portion of the distal phalanx.



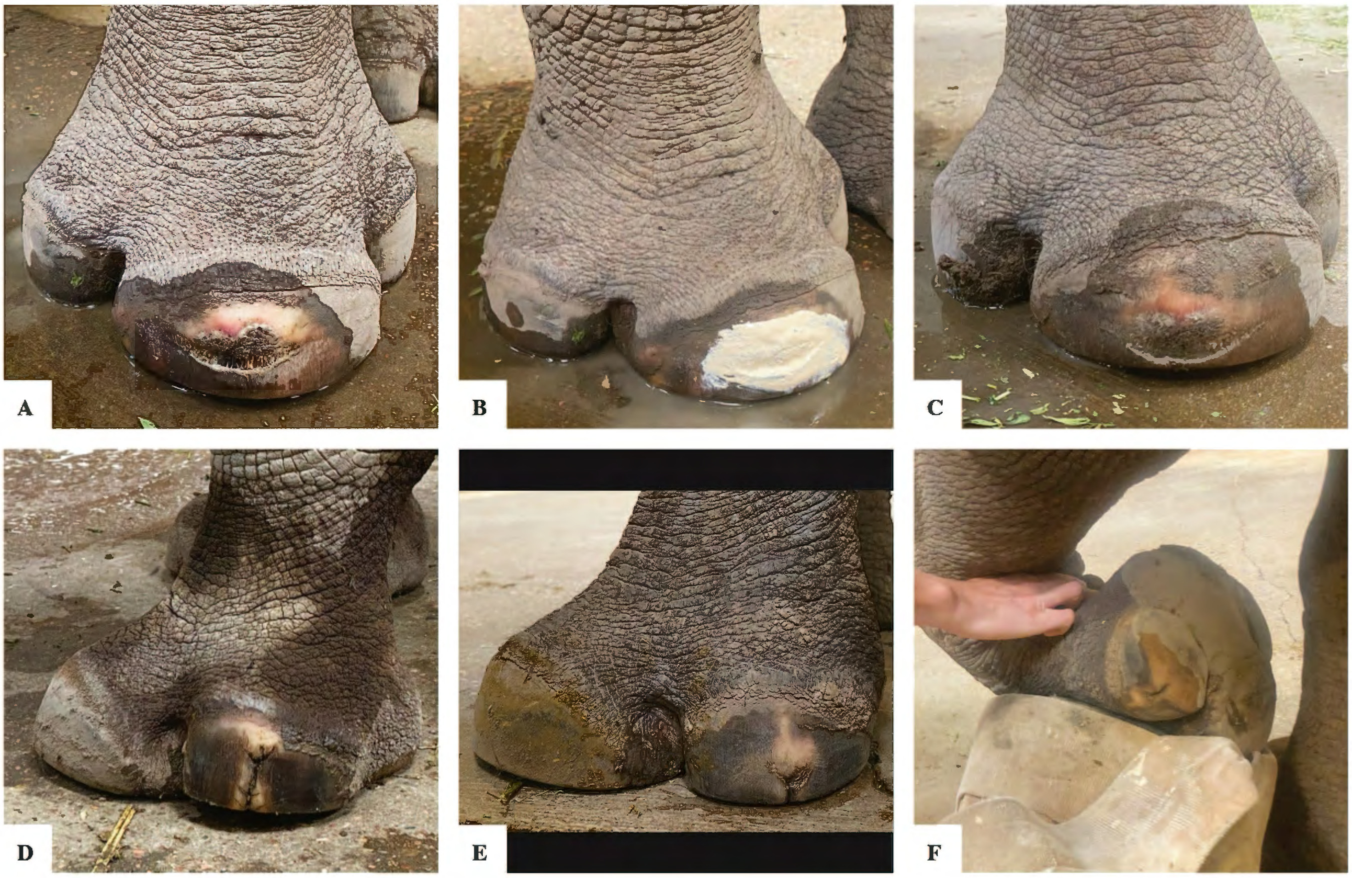
• **Figure 46.8** Subsolar abscess management for a juvenile moose *(Alces alces gigas)* with left front foot lameness. (A) Initially, the calf was positioned using food reinforcers to keep its foot in an Epsom salt foot bath. (B) Dorso-palmar radiograph of the foot showed a gas lucency (Δ) around the distal phalanx and a suspect sequestrum by the toe tip. (C) The abscess was then opened by the sole-wall junction. This location was selected as it would be less weight-bearing than the middle of the sole, allowing for faster healing. (D) The abscess extended to the toe tip so the toe tip was carefully trimmed, cleaned, and flushed. The site was packed with medical grade honey and a honey-based mud packing, with regular bandage changes. (E) Three weeks later, the toe tip opening was healing by second intention, and the lameness had nearly resolved.



• **Figure 46.9** White line disease at the sole-wall junction is often associated with bacterial or fungal infections and with humid environments. (A) In this Grevy zebra *(Equus grevyi)* with hoof and sole overgrowth, there is a gap at the sole-wall junction where opportunistic infections can occur. (B) The foot is trimmed to remove distortions and the hoof wall is rolled to minimize ongoing separation of the horn tubules at the sole-wall junction. (C) In this Somali wild ass *(Equus africanus somaliensis),* white line disease has led to a large toe tip defect. (D) To remove all infected tissue, the hoof wall toe tip is debrided until healthy lamina is apparent. The site is then treated with a disinfectant, and the foot will require regular trims.

• **Figure 46.10** Excessive sole pad wear with associated sensitivity. Note the depigmentation at the thinner region of the sole in an (A) African elephant *(Loxodonta africana)* with a conformational abnormality, (B) an okapi *(Okapi johnstoni)*, and (C) a mountain tapir *(Tapirus pinchaque)*. Both the okapi and tapir have associated erosions and ulcerations.

• **Figure 46.11** Glue-on shoes for zoo hoofstock. (A) For a Somali wild ass *(Equus africanus somaliensis)* with laminitis, this shoe distributes weight bearing to the sole and heel to decrease pressures on the laminae. (B and C) For a giraffe *(Giraffa camelopardalis reticulata)* with a fractured distal phalanx and osteoarthritis, this polyurethane shoe with cuffs serves as a splint between digits to support fracture healing and provides cushioning. Once glue is applied, the holes fill with glue and act as rivets to increase stability. (D) For an okapi *(Okapi johnstoni)*, (E) warthog (*Phacochoerus* sp.), and (F) Malayan tapir *(Tapirus indicus)* with excessive sole pad wear and foot sensitivity, these shoes protect the foot from further wear while the sole regrows.



• **Figure 46.12** Management of horizontal and vertical hoof cracks in a black rhino (*Diceros bicornis*). In this rhino, the middle digit presented with a ruptured abscess at the coronary band. (A) Six weeks later, the defect to the coronary band was visible halfway down the nail, and a partial thickness defect in the nail was observed. (B) To promote healing and prevent further infection, the nail was gently cleaned and medical grade honey was applied to the defect twice daily. (C) Three weeks later, the nail had grown, and the defect has not gotten more extensive, and this portion of the nail is almost grown out. (D) For the lateral digit with a chronic vertical nailbed crack, similar hygiene and management was initiated. (E and F) Seven weeks later, this chronic crack had also nearly grown out, suggesting a prior untreated infectious component had affected the ability to heal over the past few years.

management and benefit from daily or frequent cleanings and sometimes from wound dressings to help prevent further infection.

Lameness Diagnosis and Management

When gait abnormalities are suspected, severity of the lameness should be assessed and graded by the veterinarian. At a walk, the lack of a heel-first landing for each step is often an early indicator of foot pain. Other subtle signs of lameness may include reluctance to lay down or stand, unwillingness to shift between exhibits or from the barn, or consistently offloading weight from one leg. Both horses and nondomestic artiodactyls may use a 0 to 5 lameness scoring system.[1,32]

Foot disease is an important cause of lameness in domestic hoofstock and is probably underreported as a cause of lameness in zoo ungulates. While foot disease accounts for up to 90% of lameness in dairy cattle[33] and more than 67% of zoo elephants in North America have been reported to have foot problems,[17] the prevalence in many other species is not well documented. In some cases, thermograph may help localize temperature asymmetries associated with soft tissue or bony injuries, which may then inform additional diagnostics.[34–37]

Lameness management usually requires a combination of medical management, husbandry changes, and foot care.[1,38] Depending on severity and underlying cause, husbandry and medical management are often started prior to treatments requiring handson contact. Husbandry changes might include limiting activity, adding softer substrates such as sand,[39] and addressing potential hygiene or nutritional concerns. If clinical improvement is not seen or the lameness is worse, additional diagnostics and treatments should be done. Additional monitoring may include regular Health Assessment or Quality of Life scoring.

Many causes of lameness are associated with chronic hoof capsule distortions and subsequent damage to tendons, ligaments, joint surfaces, vasculature, and bones.[38,40] While some lameness may be associated with trauma, especially in exotic swine,[18,41] infection,[1,42] or diet,[3,20,43,44] in the authors' experience these are far less common than lameness associated with chronic hoof capsule distortions. While some examples of extensive osteoarthritis have been described with hoof overgrowth in zoo giraffe,[2,45] for most species these cases are only anecdotally observed. Notably, while laminitis has been reported, associated with nutritional imbalance (*Alces alces, C. canadensis, Camelus dromedarius, Taurotragus derbianus, Tragulus napu*)[3,20,43,44] and pregnancy *(Budorcas taxicolor tibetana, Giraffa camelopardalis tippelskirchi)*,[3] it is not as widely reported in zoo species as it has been in horses.

Therapeutic Footwear

Before applying anything to the foot, evaluate both how foot conformation or imbalance predisposed the foot to disease and how foot disease may have altered foot function.[6] The shoe may then be designed to specifically address individual factors impacting foot health, such as providing shock absorption, traction, altering pressure points, redistributing forces/leverage, or providing protection and support.[6]

Footwear should be applied after a corrective hoof trim and not to an unprepared foot. In the author's experience (Foxworth), for multiple cases where a shoe was applied without removing hoof overgrowth first, the shoe added torsional pressures resulting in partial or full avulsion of a claw. When applying a shoe, it is important to evaluate how the structures of the foot and distal limb are stressed when weight-bearing and walking and then design or adjust shoe fit to allow for healing while also preventing other injuries.[6]

Glue-on shoes and boots have been used in zoo ungulates as part of management strategies for lameness and foot disease (see Fig. 46.11). Shoes are also commonly used to help manage laminitis in horses.[6] For management of a distal phalanx fracture in a Masai giraffe *(G. camelopardalis tippelskirchi)*[46] and a lesser kudu *(Tragelaphus imberbis)*,[47] a block was glued to the nonfractured digit to allow the fracture time to heal. However, in the authors' experience, applying a shoe to one instead of both digits was associated with increased instability and ongoing lameness in a giraffe with a P3 fracture, whereas using a shoe that stabilizes across both digits (see Fig 46.11B and C) was associated with a better clinical outcome for multiple giraffe cases. Additionally, shoes, boots, and even prosthetics have been used in elephants with conformational abnormalities[48] or injuries.[49]

Conclusions

Foot disease is an important health and welfare issue for zoo ungulates. Many causes of foot disease are underreported in zoo hoofstock but are likely a common cause of morbidity and mortality. Regular routine hoof trimming practices are increasingly utilized in zoos to identify and better address foot disease and lameness. Proactive care that manages hoof overgrowth or overwear could prevent many foot diseases and causes of lameness.

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