Artykuł przeglądowy *Review*

The equine hoof in the context of use and welfare

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Summary

The equine hoof is a specialized component of the locomotor apparatus responsible for load transmission, shock absorption during movement, protection of internal structures, and sensory perception of the ground surface. Proper hoof structure and function are essential for limb biomechanics, health, functional performance, and equine welfare. The aim of this review was to present the current state of knowledge on the structure, biomechanics, and most commonly described abnormalities and diseases of equine hooves, with particular emphasis on the importance of hoof care, trimming, and shoeing. Hoof biomechanics depend on hoof shape, the proportions of individual horn structures, horn quality, and the ability of the hoof capsule to undergo controlled deformation under load. Disturbances in these elements may lead to abnormal force distribution, overloading of internal structures, lameness, and reduced comfort during use. Regular hoof assessment, proper trimming, and, when justified, appropriately selected shoeing are important components of preventing biomechanical disorders and reducing the risk of pathological changes.

Keywords: horse, equine hoof, hoof biomechanics, hoof abnormalities, hoof disorders

Evolution of the horse in the context of hoof development

The domestic horse (*Equus caballus*), as a member of the order *Perissodactyla*, is characterized by an odd number of digits (116). In contrast to the related families *Tapiridae* and *Rhinocerotidae*, the family *Equidae* developed, over the course of 55 million years of evolution, adaptations involving the gradual reduction of digits I, II, IV, and V (8). These changes were closely associated with transformations in the habitats occupied by these animals. The evolutionary nature of these modifications is supported by Vandenhout (115), who described *Hyracotherium*, a 60-million-year-old ancestor of the domestic horse, as having four digits in the forelimbs and three digits in the hindlimbs, with digit III playing the dominant role in both cases. This arrangement enabled efficient movement on soft and wet forest terrain.

Progressive climatic changes, however, led to the gradual reduction of the lateral digits, leaving the central digit protected within the hoof capsule. This adaptation favored locomotion on hard and dry steppe environments and enabled a more rapid flight response from predators (8). At the same time, these changes provided the ancestors of equids with an evolutionary advantage, reflected, among other traits, in increased body mass and improved locomotor efficiency (107).

In the modern *Equus caballus*, evolutionary processes led to the development of hoof horn at the distal end of the third digit (116). Its present form is the result of the successive reduction of digits, a feature characteristic of all members of the equid family. This process gave rise to a specialized anatomical structure – the hoof – externally surrounded by horn tissue forming the hoof capsule, which is adapted to locomotion on various types of ground. The term "hoof" therefore refers to the entire structure composed of the external horn capsule together with the bones, cartilages, neurovascular tissues, and hoof corium located within it (40). The hoof is characterized by its ability to absorb impact energy and by considerable resistance to cracking (10, 99). In addition, the presence of sensory receptors, such as Pacinian and Meissner corpuscles, allows the hoof to also function as a sensory organ capable of detecting the properties of the ground surface (12).

Hoof structure

Hoof formation begins at an early stage of embryonic development (51). According to Franciolli et al. (39), the first structures responsible for hoof development appear before day 27 of gestation, whereas the bones of the distal limb become fully visible on radiographic images at approximately day 85 of fetal development (36). Dorsally, the first external structure of the hoof is the coronary border, whose internal component is the coronary corium (41). It consists of well-vascularized horn-producing cells that form the horn of the hoof wall (29). When observed from the side, the coronary border forms an angle of 20-30° relative to the ground in hooves of horses without structural abnormalities (33, 60, 110). Below it, in direct continuity with the skin, is the epidermis of the periople, which covers the upper part of the outer layer of the hoof wall (*stratum externum*), also referred to as the glaze, and forms a protective barrier of the hoof wall (91).

The glaze forms a thin, water-resistant coating on the surface of the hoof wall, limiting moisture penetration and protecting the deeper layers of horn from mechanical damage (115). Beneath it lies the middle layer (*stratum medium*), which is also the thickest part of the hoof wall. This layer is characterized by greater density and lower moisture content externally, with the opposite properties observed in its inner part (68). It is composed of numerous cylindrical horn tubules, consisting mainly of α-keratin and embedded in an intertubular matrix. This structure has a high capacity for energy absorption and resistance to crack formation, even under substantial deformation (55). Owing to this organization, the stratum medium is primarily responsible for the mechanical strength of the hoof and its ability to absorb shock, which is important for the protection of the distal phalanx.

The layer of the hoof wall located closest to the interior of the hoof is the inner layer (*stratum internum*) (9). It is composed of epidermal lamellae that are in contact with the dermal tissue covering the distal phalanx, forming the dermal lamellae. These structures run obliquely downward and interdigitate with each other, forming a complex system of primary and secondary lamellae that provides a strong connection between the hoof capsule and the distal phalanx. An additional function of this layer is shock absorption and stabilization of the distal phalanx within the hoof capsule.

The wall of the hoof capsule is divided into three main regions: the toe, the quarters, and the heels (62). The toe has the greatest horn thickness, but it is also subjected to the highest loads during movement (111). The hard and rigid structure of this part of the wall protects the hoof against impact and compression. The quarters are characterized by variable density of tubular horn, with greater density on the medial side and lower density on the lateral side (77). The heels are located in the caudal part of the capsule and have the thinnest horn, which allows them to effectively absorb forces generated during contact between the hoof and the ground and enables slight expansion of the caudal part of the hoof under load.

On the solar aspect of the hoof, in its outer region, is the bearing border, which includes the solar edge of the wall, corresponding to the *stratum medium*, the white line as the visible part of the *stratum internum*, and part of the sole (6). The horse's body weight is supported primarily by these structures together with the frog (44). The sole is directly adjacent to the bearing border and is composed of horn that is less dense and more elastic than wall horn (48). It reaches its greatest thickness at the periphery, where it contributes to load bearing. Toward the center, however, it becomes thinner. A characteristic feature of a normally formed sole is its natural concavity, which probably results from the anatomical structure of the distal phalanx. This concavity increases traction on the ground while also supporting the absorption of forces acting during movement (15, 117).

In the center of the hoof, between the lateral and medial collateral grooves, lies the frog (40). It has the lowest elastic modulus among the horn structures of the hoof, which enables it to play an important role in shock absorption, ground-surface perception, and support of blood circulation within the hoof (12, 48). The frog is wedge-shaped, with its apex directed cranially and its base located between the heels. Together with the heels, it forms the so-called hoof pad, an elastic shock-absorbing system that allows dissipation of forces generated during contact between the limb and the ground (40). On both sides of the frog are the bars, which contact the wall horn at the bar angles (85). They function as supporting elements of the hoof, particularly during locomotion on soft or elastic ground.

The tissue responsible for hoof horn growth is the richly vascularized corium (92). It consists of five regions: the perioplic corium, coronary corium, wall corium, sole corium, and frog corium. These regions are responsible for producing the respective types of horn in the different parts of the hoof.

The main support for the entire hoof is provided by the distal phalanx (*os ungulare*) (102). Its boat-like shape largely determines the appearance and form of the entire hoof capsule (22). The anatomical features of this bone include, among others, the extensor process, dorsal surface, solar margin, solar surface, and palmar processes. The deep digital flexor tendon attaches to the flexor surface.

Behind the distal phalanx, between its palmar processes, lies the distal sesamoid bone, protected by the navicular bursa (118). It plays an important role in the function of the deep digital flexor tendon by reducing tension generated during its action. Above it lies the middle phalanx (*os coronale*), which, together with the distal phalanx, forms the distal interphalangeal joint (86). This joint enables movement primarily in one plane: flexion and extension of the digit.

The ungual cartilages are located adjacent to the palmar processes of the distal phalanx and allow elastic

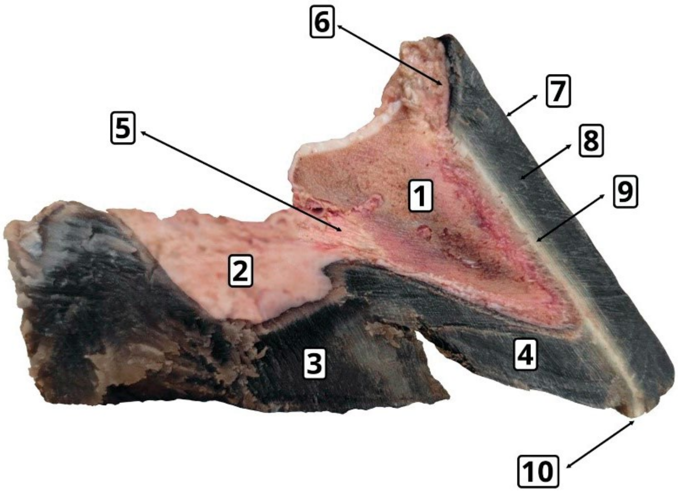

Fig. 1. Anatomical section of the equine hoof showing the relationship between the hoof capsule and the distal phalanx
Explanations: 1 – distal phalanx/coffin bone (*phalanx distalis; os ungulare*); 2 – digital cushion (*torus digitalis*); 3 – frog (*cuneus ungulae*); 4 – sole (*solea ungulae*); 5 – insertion area of the deep digital flexor tendon; 6 – coronary corium; 7 – outer layer of the hoof wall (*stratum externum*); 8 – middle layer of the hoof wall (*stratum medium*); 9 – inner layer of the hoof wall/lamellar region (*stratum internum*); 10 – white line. The section illustrates the position of the distal phalanx within the hoof capsule and the main horn, corium, and soft-tissue structures described in the text.

hoof function during locomotion (20). Between them lies the digital cushion (*torus digitalis*), which plays an important role in shock absorption, protection of the distal sesamoid bone, and support of blood transport within the hoof (70).

During locomotion, the deep digital flexor tendon, located in the caudal part of the digit, plays an important role (56). It is responsible for flexion of the distal interphalangeal joint and shock absorption at the moment of limb contact with the ground. On the dorsal aspect of the digit runs the common digital extensor tendon (3). Ligamentous connections between the individual bones stabilize the entire locomotor apparatus within the hoof (40). The anatomical arrangement of the main horn, corium, soft-tissue, and skeletal structures of the hoof is presented in Figure 1.

Because hoof horn grows continuously, the hoof region has a well-developed vascular system (76). Blood is supplied by the palmar arteries – the lateral and medial digital arteries. At the level of the middle phalanx, they form the coronary circumflex artery, from which numerous smaller vessels branch to supply the hoof tissues. The venous network forms three large plexuses: the solar plexus, marginal plexus, and coronary plexus (11). During locomotion, the pressure exerted on these structures supports blood circulation within the hoof, acting as a pump that facilitates venous return.

Biomechanical functions of the hoof

with evolution and the development of the modern hoof at the distal end of the third digit in the forelimb and hindlimb, this structure assumed a key supportive and shock-absorbing function in the equine limb (45). The transformation of the limb into a specialized locomotor apparatus capable of efficiently transmitting substantial dynamic loads was an important factor that enabled equids to develop strategies for rapid and sustained movement across open environments. Owing to the effective connection between hoof horn, connective tissues, and skeletal structures, horses gained a biomechanical advantage over their ancestors, whose limbs had a multidigit structure (116). This organization of the hoof apparatus allowed effective absorption and dissipation of forces generated during contact with the ground, while also protecting delicate internal tissues and osteoarticular structures (67).

In this complex system, the biomechanical properties of the hoof result from its specific structure, in which individual tissues perform specialized but complementary functions (27, 113). The integration of horn structures, soft tissues, and skeletal elements enables effective force distribution, absorption of kinetic energy, and stable support during both the static and dynamic phases of movement. Hoof biomechanics therefore does not depend on the action of a single element, but rather on the cooperation of the entire system, in which disruption in one region may lead to compensatory changes in the remaining structures.

The external part of the hoof is formed by the hoof wall, which, because of its differentiated histological and functional structure, is divided into three layers: the outer layer (*stratum externum*), middle layer (*stratum medium*), and inner layer (*stratum internum*) (6). The *stratum externum* primarily serves a protective function, forming a barrier that protects the deeper layers against environmental factors, particularly excessive moisture penetration and mechanical damage. Despite its relatively small thickness, this layer plays an important role in maintaining the integrity of the hoof capsule.

The thickest and biomechanically most important part of the wall is the *stratum medium*, which is mainly responsible for the hoof's ability to resist shear and compressive forces (96). The mechanical properties of this layer result from the tubular structure of hoof horn, in which keratin tubules are surrounded by an intertubular substance with distinct physical properties. The gradual increase in water content in the deeper regions of the *stratum medium* influences this layer's capacity for elastic deformation, which is important for shock absorption during dynamic loading.

The *stratum internum*, composed of primary and secondary lamellae, together with the dermal tissue of the wall, forms a direct connection between the hoof capsule and the distal phalanx (65). This arrangement is responsible not only for suspending the distal phalanx within the capsule, but also for damping vibrations generated during movement. The integrity of the lamellar connection is essential for proper function of the locomotor apparatus, because it stabilizes the position of the distal phalanx and prevents its rotation and displacement within the hoof capsule (105).

The hoof is subjected not only to vertical forces, but also to substantial horizontal forces, especially during braking, turning, and propulsion phases (49). The structures primarily responsible for reducing these forces are the bars and bar angles. They stabilize the caudal part of the hoof and support the proper function of the deep digital flexor apparatus. Appropriate length and shape of the bars are important for maintaining the shock-absorbing function of the caudal hoof and for providing proper support to the distal phalanx during movement (85).

In direct proximity to the bars are the sole and frog, which play important roles in hoof biomechanics (23). The sole, as a horn tissue with a lower elastic modulus than the hoof wall, is responsible for dissipating vertical forces and stabilizing the hoof on the ground (98). Its characteristic arched shape increases load-bearing and shock-absorbing capacity, allowing effective transfer of loads to the hoof wall. The frog, which has the lowest elastic modulus among the horn structures of the hoof, plays a key role in energy absorption and adaptation to irregularities of the ground surface. Together with the sole, it also participates in regulating blood flow within the hoof, acting as a supporting element of the venous pump mechanism (73). Contact between the frog and the ground promotes cyclic pressure changes in the soft tissues, facilitating venous outflow from the digit.

Another important element of the hoof's shock-absorbing system is the digital cushion, which is composed of fibro-fatty tissue and, together with the frog, is responsible for reducing vibrations and compressive forces generated during contact with the ground (11). Studies have shown that a better-developed digital cushion increases the capacity of the caudal part of the hoof to expand under load, which reduces overload acting on the distal interphalangeal joint and internal structures (62). The mechanism of expansion and contraction of the hoof capsule enables energy redistribution and supports blood circulation, acting as a pump that facilitates venous return from the limb. This phenomenon becomes particularly important during intense exercise, such as galloping or jumping, when the forces acting on the hoof may exceed the horse's body weight several times (1).

A factor determining hoof behavior during movement is its internal skeletal architecture (112). The distal phalanx, distal sesamoid bone, and distal part of the middle phalanx form a system capable of effectively dissipating forces generated during loading. The trabecular structure of the distal phalanx reflects the dominant directions of mechanical loading, indicating its adaptation to a shock-absorbing function (33). The distal sesamoid bone, in turn, acts as a pulley that changes the course of the deep digital flexor tendon, allowing controlled force transmission and gradual damping during the landing phase (103).

The navicular apparatus, which includes the impar and collateral ligaments of the distal sesamoid bone, also plays an important role in hoof biomechanics (118). These structures stabilize the position of the distal sesamoid bone under increased loading and regulate the pressure exerted by the deep digital flexor tendon on its surface. Disturbances within the ligamentous apparatus lead to abnormal distribution of compressive forces, promoting the development of degenerative changes and pain syndromes involving the distal sesamoid bone. Thus, the ligaments constitute an important link between anatomy and biomechanics, being responsible for the controlled transfer of energy between the hoof and the more proximal parts of the limb.

Hoof biomechanics also depends on hoof shape, the length of individual horn structures, and the ability of the hoof capsule to undergo controlled elastic deformation (35). Under physiological conditions, the hoof is capable of controlled elastic deformation in both the vertical and transverse planes (54). This deformation includes expansion of the heels, bending of the hoof wall, and compression of the soft tissues in the caudal part of the hoof. This mechanism allows absorption of kinetic energy generated at the moment of ground contact and its gradual dissipation during the stance phase.

The biomechanical response of the hoof is also influenced by external conditions, particularly the type of ground surface, the intensity and character of use, and the method of hoof management. Hard surfaces may increase impact forces acting on the hoof capsule, whereas soft or deformable ground modifies the duration and distribution of contact between the hoof and the substrate (113). In sport horses, repeated loading during galloping, jumping, turning, or work on variable surfaces may increase the importance of proper hoof balance and of the coordinated function of the wall, sole, frog, digital cushion, and navicular apparatus (35, 111, 113). Shoeing may protect the hoof wall against excessive wear and improve traction under specific conditions, but it may also alter hoof loading patterns and restrict the natural expansion of the hoof capsule during weight bearing (47, 54). Therefore, the biomechanical function of the hoof should be interpreted not only in relation to its anatomical structure, but also in the context of ground conditions, use, trimming, and shoeing.

Hoof abnormalities and diseases

disturbances in the structure, proportions, or balance of the hoof capsule may impair the physiological distribution of forces within the distal limb and predispose the horse to overload-related and pathological changes (27, 35, 73, 113). For this reason, hoof abnormalities and diseases should be considered not only as local disorders of the hoof capsule, but also as conditions that may affect locomotor efficiency, comfort, and welfare (73, 75).

In medicine, the term “abnormality” refers to structural or functional irregularities that develop during fetal life, are present at birth, and may subsequently lead to anatomical changes, functional disturbances, or both (28). Abnormalities can be divided into major and minor categories. Major abnormalities refer to structural or functional defects that have a significant effect on health status and survival, as well as on mobility or cognitive function. Minor abnormalities, in contrast, are structural or functional changes that have no effect, or only a limited effect, on health status. Another classification distinguishes structural and functional abnormalities. The former involve changes in the structure of body parts, such as limb malformations. Functional abnormalities, in turn, refer to disturbances in the function of organs or biological processes that do not manifest as structural changes but nevertheless affect the functioning of the organism.

With regard to the equine hoof, Łuszczyński et al. (72) divided abnormalities into conformational defects and disorders. Conformational defects refer to deviations in the shape of the hoof capsule, its orientation, or the general structure of the hoof, arising mainly from anatomical and genetic predispositions. Disorders, by contrast, are pathological or environmental changes resulting from external factors and belong to acquired changes that develop during the horse’s life. A similar classification was proposed by Çınar and Şirin (21), who, in goats, distinguished congenital abnormalities, present at birth or resulting from genetic predisposition, and acquired abnormalities, developing during the animal’s life under the influence of environmental, mechanical, or management-related factors.

According to Łuszczyński et al. (72), more than 60% of the horse population has at least one defect in hoof structure or function, with conformational defects accounting for more than 65% and pathological abnormalities for approximately 35%. The most commonly observed hoof conformation defects include asymmetries, flat hooves, wide hooves, valgus hooves, excessively narrow hooves, an overly long toe, low heels, and disturbances of the digit axis relative to the distal interphalangeal joint (52, 72, 101). Improper hoof care may promote the development of hoof capsule deformities, such as contracted heels, asymmetries of the hoof wall, and disturbances of the digit axis (4, 46). Any asymmetries or disturbances in proportions may lead to further pathological changes, because they result in overloading of limb structures and changes within the joints, consequently affecting the entire locomotor system (52). A key aspect of hoof apparatus function is hoof balance, which plays an important role in locomotor efficiency and protection of limb structures (64). Hooves with a disproportionately small hoof capsule are particularly undesirable, because the reduced bearing surface increases local pressure, thereby increasing the risk of dysfunction, including lameness (100). Deviations from normal hoof angulation values may lead to disturbances in the distribution of forces acting on limb structures and to an increased risk of overload and injury.

It should also be noted that hoof capsule defects are observed not only in horses used by humans, but also in free-ranging individuals (74). These authors observed that all examined feral horses on Sable Island in Canada had at least one abnormality in hoof conformation. These findings suggest that the so-called “ideal hoof capsule shape” does not necessarily represent a single rigid standard, but may to some extent depend on adaptation to environmental conditions.

Holzhauer et al. (53) indicated that the most common hoof diseases in horses include thrush, minor cracks, visible rings on the hoof wall, sole bruising, deep cracks extending into the hoof, white line disease, widening of the white line, horizontal cracks, chronic laminitis, cracks in the lateral walls of the hoof capsule, keratoma, and equine canker. These authors noted, however, that although approximately 85% of the examined horses showed at least one of these conditions, most cases were mild and did not cause evident clinical signs. Similar findings were reported by Shin et al. (106) in a population of racing and recreational horses. In their study, the most frequently observed abnormality was thrush, although its prevalence was relatively low and did not exceed 5% of the examined animals.

Regular hoof cleaning enables the removal of organic debris and microorganisms that may promote infection, including processes associated with thrush (50, 63). Prolonged exposure to excessive moisture may lead to softening of the horn and disruption of its integrity, whereas an excessively dry environment promotes cracking and increased brittleness (18, 57). Lack of hygiene has been identified as one of the factors increasing the risk of hoof diseases, such as thrush, as well as reducing hoof horn quality (16).

Thrush is a nonproliferative pododermatitis of the frog horn caused by the proliferation of pathogenic microorganisms within the frog, particularly anaerobic bacteria (82). According to Petrov and Dicks (87), the condition may result from a polymicrobial infection, particularly involving *F. necrophorum*. At the same time, the authors suggested that the condition occurs without the involvement of *D. nodosus*, which is considered the main cause of foot rot in other animal species. Infection develops as a result of prolonged contact with moisture and contamination, such as mud and manure. However, it may also result from impaired self-cleaning mechanisms caused by insufficient movement or hoof conformation defects that create spaces into which debris can penetrate. Such causes include, among others, club feet and low heels. Thrush may also contribute to bacterial invasion of the frog corium and digital cushion, potentially causing pain and lameness (82).

The hoof is subjected not only to vertical forces, but also to substantial horizontal forces, particularly during braking, turning, and propulsion phases (49). The structures responsible for reducing these forces include the bars and bar angles, which stabilize the caudal part of the hoof (85). Disturbances in these structures and abnormal force distribution may lead to hoof wall cracks. An excessively dry environment and impaired hoof balance further increase the risk of horizontal cracks and horn damage (57).

Cracks within the hoof wall are divided into vertical cracks and horizontal cracks (83, 77). They are classified according to location, depth, and length. These lesions may occur at any site on the hoof capsule, on either the medial or lateral side. The term "partial" refers to cracks beginning either at the coronary band or at the bearing border, whereas "complete" cracks extend along the entire length of the hoof wall. According to depth, cracks may be classified as superficial or deep. Superficial lesions involve only some superficial layers of the hoof wall and do not extend through its full thickness. Deep lesions, in contrast, include cracks and fissures extending through the full thickness of the wall to the internal structures. In addition, based on crack morphology, cracks may be distinguished as those extending from the outside into the depth of the hoof or those extending from the internal hoof structures outward.

The navicular apparatus, which includes the distal sesamoid bone, navicular bursa, deep digital flexor tendon, and associated ligaments, plays an important role in the biomechanics of the palmar part of the hoof (118). The deep digital flexor tendon passes over the palmar surface of the distal sesamoid bone and generates compressive forces in this region, particularly during the stance and breakover phases of movement. For this reason, disturbances in hoof balance and conformation may alter the loading pattern of the navicular apparatus and contribute to chronic overload of the distal sesamoid bone and surrounding soft tissues (35, 118). Navicular syndrome can therefore be regarded as an example of a disorder in which biomechanical imbalance, repeated loading, and degenerative changes are closely interrelated. Clinically, this condition is associated with palmar foot pain, lameness, shortening of the stride, and reduced functional capacity of the horse, which makes it relevant not only to locomotor biomechanics but also to welfare.

Laminitis also remains an important clinical problem and is one of the most serious diseases of the equine hoof apparatus. This term refers to an aseptic inflammatory and degenerative condition affecting the lamellar tissue of the hoof wall, resulting in weakening and mechanical stretching of the connection between the inner and outer lamellae (7, 66). Contemporary classifications most commonly distinguish endocrinopathic, sepsis-related, and supporting-limb laminitis, which differ in their initiating mechanisms but share disruption of the suspensory apparatus of the distal phalanx as a key clinical consequence (37). Particular attention is currently paid to endocrinopathic laminitis, in which insulin dysregulation, equine metabolic syndrome, and pituitary pars intermedia dysfunction are important risk factors (30, 37).

At the tissue level, laminitis involves pathological changes within the lamellar interface, including damage to the basement membrane and disturbances in the attachment between epidermal lamellar cells and the underlying dermis (84, 90). Uncontrolled or dysregulated activity of matrix metalloproteinases may contribute to degradation of extracellular matrix components and weakening of the lamellar connection (84, 66). Under the influence of forces generated by the animal's body weight and the tension of the deep digital flexor tendon, this weakening may lead to rotation or sinking of the distal phalanx within the hoof capsule (66). In severe cases, complete disruption of the lamellar connection may occur, resulting in substantial structural instability of the hoof apparatus.

Laminitis is therefore not only a local disease of the hoof, but also a major welfare problem. It is associated with severe pain, lameness, reduced mobility, reluctance to move, and loss of functional capacity, often preventing the horse from returning to previous use (66, 88). In chronic or treatment-resistant cases, persistent pain and irreversible structural changes may make euthanasia necessary (66).

Pathological hoof conditions also include white line disease, keratoma, and equine canker (53). White line disease is a keratolytic process leading to separation of the inner hoof wall from the sole (93). In the early stages of the disease, the white line becomes wider, distinctly softer, and chalky in appearance. In addition, the sole may become flatter and more sensitive. White line disease is associated with the presence of keratinolytic bacteria and fungi (59). However, because of the large number and diversity of isolated organisms, they are probably secondary opportunists. Predisposing factors include excessive environmental moisture, improper nutrition, trimming and shoeing errors, hoof horn defects, lack of regular care and stable hygiene, and unfavorable hoof morphology, such as poor horn quality and a shallow, abnormally angled hoof wall.

Keratoma is a compact keratinous mass with a cylindrical, elongated, conical shape, occurring between the hoof wall and the distal phalanx (5, 42, 95). At the affected site, deformation and displacement of the white line usually occur (19). It is a benign neoplastic lesion resulting from abnormal proliferation of tissues containing keratin and squamous epithelial cells (42, 95). Pressure exerted by the keratinous mass leads to areas of resorption in the distal phalanx, resulting in deformation of the hoof capsule and lameness. The condition is usually unilateral, and its etiology is not fully understood (5). It is presumed to be associated with previous trauma. Keratoma-like lesions, in turn, may develop as a result of a chronic or infected hoof wall abscess that ruptures toward the coronary band.

Equine canker is a disease characterized by excessive proliferation of horn tissue covered with a cottage-cheese-like exudate, often foul-smelling and prone to bleeding after trauma (2). The lesions are pathognomonic and initially involve only the frog, but may subsequently spread to other parts of the hoof. The risk of the condition is greater in moist and unhygienic housing conditions, although the exact causes are unknown (2, 79). Its etiology may be associated with anaerobic bacteria, spirochetes, fungi, viruses, or an immune-mediated reaction. Despite its name, equine canker is not considered a neoplasm, but rather a chronic inflammatory or immune-mediated reaction (2).

Taken together, hoof abnormalities and diseases may disturb the distribution of forces within the distal limb and lead to altered gait patterns, movement asymmetry, overload of internal structures, and an increased risk of injury (73, 104, 109, 120). The most common clinical consequence of these disturbances is lameness, understood as abnormal gait or posture resulting from pain or dysfunction of the locomotor system (26, 75, 78). In this context, hoof disorders should not be considered only as local pathological changes, but also as conditions that may reduce the horse’s comfort, functional capacity, and welfare.

Importance of hoof care procedures

proper function of the equine hoof results from the complex interaction between anatomical structure, the material properties of hoof horn, mechanical loading, and environmental factors (18, 90). Hoof care procedures play an important role in shaping these relationships because, through direct intervention in the structure of the hoof capsule, they influence its functional properties and its ability to adapt to variable conditions of use. Scientific studies clearly indicate that improper hoof care may promote the development of hoof capsule deformities, such as contracted heels, hoof wall asymmetries, and disturbances of the digit axis (4, 46). Even if these changes do not initially manifest clinically, in the long term they may lead to disturbances in limb biomechanics and an increased risk of lameness (24, 34).

The hoof capsule forms the external layer of the hoof, whose primary function is to protect internal structures and distribute loads generated during movement, particularly during high-speed locomotion (51). Therefore, any deformities or morphological or histological changes within the hoof capsule may disrupt the integrity of the entire structural-functional complex of the hoof apparatus. It has also been shown that hoof conformation parameters are associated with the occurrence of lameness in horses (73).

Hoof care includes a broad range of practices, such as trimming, shoeing, hygiene maintenance, moisture control, and the use of hoof care products, all aimed at maintaining optimal hoof properties and reducing the risk of pathological changes. Trimming is a fundamental component of hoof prevention and correction, determining the maintenance of proper hoof capsule geometry and balance among its individual structures (4, 81). Regular shortening of the hoof wall and shaping of the sole and frog influence the way forces acting on the limb are transmitted during the stance and propulsion phases (35, 119). Changes in hoof wall length and hoof angles modify the distribution of pressure within the sole, frog, and internal structures, which may either improve or worsen biomechanical conditions, depending on whether the procedure is performed correctly.

In the context of hoof biomechanics, particular importance is attributed to maintaining proper hoof balance (98). Hoof balance is a key aspect of hoof apparatus function and plays an important role in locomotor efficiency and protection of limb structures. However, this concept does not have a single clearly defined definition. It may be described as a geometric state of the hoof capsule that improves the horse’s locomotor efficiency and minimizes the loads acting on limb structures (64). Turner (114) defined balance as correction of the hoof capsule in such a way that the bearing surface of the hoof is positioned as close as possible to the center of the limb. A properly balanced hoof is characterized primarily by a proportional size relative to body height and weight and by a conical shape (108). Hooves with a disproportionately small hoof capsule are particularly undesirable, because a reduced bearing surface increases local pressure and thus increases the risk of dysfunction, including lameness (100). Hoof angulation is also an important component of hoof conformation assessment. The hoof-pastern axis angle should be approximately 45-55° in the forelimbs and approximately 60° in the hindlimbs (73). Deviations from these values may lead to disturbances in the distribution of forces acting on limb structures and to an increased risk of overload and injury.

The literature emphasizes that properly performed trimming supports physiological deformation of the hoof capsule under load, which plays a key role in shock absorption and in supporting blood circulation within the hoof corium (11, 14). At the same time, excessive intervention in the sole or frog may weaken the protective function of these structures, increasing the hoof's susceptibility to mechanical injury and adaptive disturbances (25, 94). For this reason, it is recommended that the extent of trimming be individually adjusted to the rate of horn growth, the horse's body weight, the type of ground, and the intensity of use (34, 80).

The need for regular hoof correction is directly related to the continuous growth of hoof horn. The hoof wall of adult horses is commonly reported to grow at approximately 8-10 mm per month, although the rate of growth may vary depending on age, health status, season, nutrition, exercise, and individual predisposition (18, 34, 89). Because the distance from the coronary border to the bearing border is greatest at the toe and shorter in the quarters and heels, complete replacement of the wall horn takes the longest in the toe region and occurs more rapidly in the caudal parts of the hoof capsule. In practical hoof management, this means that trimming and shoeing intervals should not be treated as fixed values, but should be adjusted to the rate of horn growth, hoof wear, hoof balance, and the way the horse is used. In working and sport horses, regular farriery intervals of approximately 4-6 weeks have been shown to support the maintenance of foot balance and may reduce excessive loading of palmar hoof structures (71). In less intensively used barefoot horses, the interval may sometimes be longer, provided that hoof balance, wall length, and horn wear remain within physiological limits (18, 34, 80).

Shoeing, as a supplement to trimming, has a significant effect on hoof function by altering the nature of contact with the ground and modifying the loads acting on the hoof capsule (21, 54). The use of horseshoes may limit excessive wear of the hoof wall and improve limb stability under specific conditions of use (13, 31). At the same time, studies indicate that horseshoes may restrict the natural expansion of the hoof capsule and reduce the contribution of the frog and digital cushion to shock absorption. Comparisons between shod and barefoot horses have shown differences in the adaptation of horn structures to mechanical loads and environmental conditions (43, 47). Therefore, a long-term hoof care approach may lead to the stabilization of specific morphological and functional hoof characteristics, emphasizing the importance of a deliberate and consistent choice of the appropriate management method (32, 81).

Maintaining appropriate hoof hygiene is also an important aspect of hoof care, as it determines hoof horn quality and resistance to biological factors (50, 63). Regular hoof cleaning enables the removal of organic debris and microorganisms that may promote infection, including processes associated with thrush. Environmental conditions, particularly ground moisture, play an important role in shaping horn properties by affecting its structure and mechanical resistance (69, 97). Prolonged exposure to excessive moisture may lead to horn softening and disruption of its integrity, whereas an excessively dry environment promotes cracking and increased brittleness (18, 57). Hoof care practices, including control of housing conditions and the use of appropriate protective products, may reduce the negative effects of extreme environmental conditions, although their effectiveness may vary (58, 97).

Hoof care products, such as oils, greases, and moisturizers, are used to improve horn condition and protect it against external factors (68, 90). However, studies indicate that their action is often limited to the superficial layers of the horn, and long-term effects depend on chemical composition and frequency of application. Excessive or inappropriate use of such products may disturb the natural moisture balance of the horn, which highlights the need to treat them as a supplementary rather than primary element of hoof care (18, 34).

Hoof abnormalities and the functional value and welfare of horses

the functional value of horses is closely related to the ability of the locomotor apparatus to transmit loads efficiently and without pain. Because the hoof forms the distal support structure of the limb, abnormalities of its shape, proportions, horn quality, and balance may affect not only local hoof function, but also the mechanics of the entire limb. Changes in hoof conformation may disturb the alignment of the distal limb, alter force distribution during stance and movement, and increase the risk of overload-related injuries and lameness (38, 73, 104).

From a practical perspective, hoof disorders reduce the horse's functional capacity by limiting movement efficiency, shortening stride length, increasing movement asymmetry, and decreasing tolerance of exercise or work. These consequences are particularly important in sport and working horses, in which repeated loading, turning, jumping, or movement on variable surfaces increases the mechanical demands placed on the hoof capsule and internal hoof structures (35, 51, 113). Even mild abnormalities may therefore become clinically relevant when they persist over time or occur together with inappropriate trimming, shoeing, unsuitable ground conditions, or excessive workload.

Hoof abnormalities and diseases are also directly related to welfare. Painful conditions of the hoof apparatus may lead to lameness, reduced willingness to move, changes in posture, avoidance of normal activity, and difficulty maintaining normal use. Lameness should therefore be regarded not only as a clinical sign, but also as an indicator of impaired comfort and reduced welfare (26, 75, 78). This is particularly evident in chronic or recurrent hoof disorders, such as laminitis, navicular syndrome, advanced hoof wall cracks, white line disease, or severe infections of the frog, where pain and structural damage may persist despite treatment.

For these reasons, hoof care has a preventive and welfare-related function. Regular assessment of hoof conformation, balance, horn quality, wear pattern, and signs of pain allows early detection of abnormalities before they develop into permanent deformities or clinically significant lameness (51, 61, 73). Appropriate trimming, individually adjusted shoeing, hygiene, nutrition, access to movement, and suitable ground conditions should therefore be considered complementary elements of maintaining both the functional value and welfare of horses (16, 17, 34, 80).

Conclusions

The equine hoof is a highly specialized biomechanical structure whose proper function depends on the coordinated interaction of the hoof wall, sole, frog, digital cushion, lamellar apparatus, and internal skeletal structures. Disturbances affecting any of these components may alter force distribution within the distal limb and impair locomotor function.

Hoof abnormalities and diseases should be considered not only as local pathological changes but also as factors influencing the functional value, performance, and long-term soundness of horses. Conditions such as laminitis, navicular syndrome, hoof wall defects, and infectious diseases of the hoof may result in pain, lameness, and progressive deterioration of locomotor function.

The relationship between hoof health and welfare is inseparable. Painful hoof disorders reduce comfort, limit normal movement and use, and may significantly compromise the welfare of affected horses. Early recognition of abnormalities and appropriate intervention are therefore essential from both clinical and welfare perspectives.

Regular hoof assessment, individually adapted trimming and shoeing, proper hygiene, suitable environmental conditions, and appropriate management practices remain the most important measures supporting hoof health and reducing the risk of pathological changes. Maintaining hoof integrity should therefore be regarded as a fundamental element of responsible horse management and welfare.

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