# "Iron and fire": history and advances of mule shoeing

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## SUMMARY

During the last decades in Europe and the United States there has been a renewed interest in the use of the mule. This review summarizes the scarce information available in the veterinary literature on the anatomical particularities and shoeing techniques of the mule's hoof that have an important impact on the health and welfare of the animal. Compared with the horse the mule's hoof has a distinctive upright dorsal wall angle and a broken forward hoof-pastern axis; the cartilages of the distal phalanx are much more developed towards the palmar/plantar parts of the hoof; the inclination degree of the hoof wall to the ground, at the toe, the quarters and heels is almost vertical; the sole has elevated moisture content in its deep layers and the horn tubules are more evident; the coronary dermis together with the large coronary groove are higher; the laminar dermis of the wall segment is less extended; the mule's hoof is smaller, longer and narrower. The mule's shoes display a web of greater and uniform thickness over their entire extension compared to the horse's. The toe of the front shoe is rounded, fitted slightly wider and turned up; and its outline fitting is marginally wider on the toe and on the external branch. The front shoe coverage, therefore, is slightly wider at the toe, and gently decreases to the toe quarters, heel quarters and heels; moreover, the internal branch is narrower than the outside. The hind shoe shows the same characteristics of the front one, plus some distinct features such as a larger blunt toe, equal full outline fitting proportions, and identical branch coverage.

## KEY WORDS

Muline, hoof, anatomy, farriery, shoe.

## INTRODUCTION

In the past, mules have assisted man in daily activities from agriculture, to trade, to military service. In recent decades, the mechanization of farming and the demobilization of some local mountain armies have contributed to a significant decline in the mule population. Recently, there has been a renewed interest in the use of this animal to carry lumber within parks and for trekking tourism activities[1]. In zootechnical terminology, the mule is a domestic equine hybrid resulting from a cross between a mare (female horse) and a jack (male donkey) while the hinny is the offspring of a jennet (female donkey) and a stallion (male horse)[1,2]. From the donkey, the mule inherits an ideal hoof structure and conformation to support agricultural work or face paths on steep and inaccessible terrains. Hinnies play an important role in drier areas and are used mainly as work animal. Over time, the anatomical peculiarities of the hoof and the types of work required of the animal have lead the art of farriery to a high degree of specialization. The purpose of this paper is to provide an overview of the scarce information available in the veterinary literature about functional anatomy and shoeing techniques of the mule's hoof compared with the horse.

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## ANATOMY OF THE MULE'S HOOF: BASIC DIFFERENCES COMPARED WITH THE HORSE

In the art of farriery (Mascalcia in Italian) the distal end of the digit is called the "hoof" (colloquial terms: fore-foot and hind-foot). In anatomical language, the middle-distal extremity of the equine limb is the *manus* in the thoracic limb (carpus, metacarpus and digit) and the *pes* in the pelvic limb (tarsus, metatarsus and digit)[3,4,5,6]. They are the anatomical regions of greatest interest for shoeing, although a general examination of the animal should not be neglected by focusing exclusively on the distal extremity of the limb. The evaluation of overall conformation, the correct alignment of the skeletal components of the limb, and movement at different gaits are essential.

In equestrian terminology, the term "hoof" or "*ungula*" refers to the horny hoof capsule as well as all the structures within: the sensitive dermis (*corium*), digital cushion (frog and bulb portions), distal phalanx (coffin bone), most of the collateral cartilages of the distal phalanx (lateral and medial foot cartilages), distal interphalangeal (coffin) joint, distal parts of the middle phalanx (short pastern bone), distal sesamoid (navicular) bone, podotrochlear bursa (navicular bursa), tendons of insertion of the common digital extensor and deep digital flexor muscles, and numerous ligaments, blood vessels, and nerves[7,8,9,10,11,12,13].

The mules and donkeys usually have a distinctive upright dorsal hoof wall angle and often a broken forward hoof-


**Figure 1** - Lateral view of the mule hoof, left hindlimb (punta = toe, mammella = toe quarter, quarto = heel quarter, tallone = plantar heel).

pastern axis[14,15]. The cartilages of the distal phalanx are much more developed towards the palmar/plantar parts of the hoof compared with the horse[4]. The almost vertical inclination degree of the hoof wall to the ground, at the toe, the quarters and heels is always less accentuated than in the horse[4].

When the hoof is on the ground, it is possible to identify different areas on the external surface of the hoof capsule: the lateral view shows the coronary border, the perioplic band, the heel bulbs and the wall. The hoof wall can be divided into the dorsal toe, the toe quarters (medial and lateral), the heel quarters (medial and lateral), and the palmar or plantar heels (Figure 1).

In the mule, the perioplic band (*stratum externum* of the hoof wall) presents a particular development, extending beyond the heels, up to their angle of inflection (bar of the heel)[3,4]. The solar surface of the hoof includes the bearing margin of the wall, the sole, the frog, the bars, and a well-defined zone called the white line (*zona alba ungulae*). The white line represents the transition between the horn of the hoof wall and the horn of the sole and is an important anatomical landmark for the farrier (Figure 2).

The sole of the mule has an elevated moisture content in its deep layers, and the horn tubules are more evident than in the horse[4]. The coronary dermis (*corium coronae*) supplies the epidermis that forms the thickest layer of the hoof wall (*stratum medium*), and together with the large coronary groove are higher than in the horse[4]. The inner layer of the hoof wall (*stratum internum or lamellatum*) consists of several primary epidermal lamellae (laminar horn) which extending down perpendicularly from the distal border of the coronary groove, dovetail with the dermal lamellae (laminar dermis) in a very strong union (interdigitations of epidermal and dermal laminae)[12,16]. The sole dermis (*corium solae*) is thinner and covered with long papillae. The distal end of each dermal lamella raises many papillae known as the terminal papillae. The horn tubules produced from these papillae together with the laminar horn originate the white zone, which is the dividing line of epidermal sole-wall junction[16] and is used as a guide for positioning nails with shoeing. In the mule, relative to the parietal surface of the distal phalanx the laminar dermis of the wall segment (*corium parietis*) is less extended than in the horse, with a lower average ratio 1:2 than 1:3, 1:4 in the horse; these laminae even if less numerous are thicker and more vascularized[4]. In the horse there are approximately 550 primary dermal laminae, 450 in the mule and 350 in the donkey[4]. The growth of the hoof wall progresses at the rate of about 8 mm per month, with a range between 3.98 and 13.6 mm all around the coronet. On average, complete hoof wall renewal takes approximately 8-16 months at the toe, 6-10 months at the toe quarters and 4-6 months at the heel quarters[7].

In the horse, the lateral and medial side of the wall are quite oblique with a convergence in a proximal direction, and the angles to the ground of the dorsal hoof wall and of the wall at the heel are parallel with about 47 degrees and in continuity with the inclination of dorsal aspect of the pastern; the shape of the hoof in its solar aspect is almost rounded in the horse. The mule has inherited the conformation and the structure of the hoof from the donkey. The mule's hoof is smaller, longer and narrower compared to the horse: the lon-

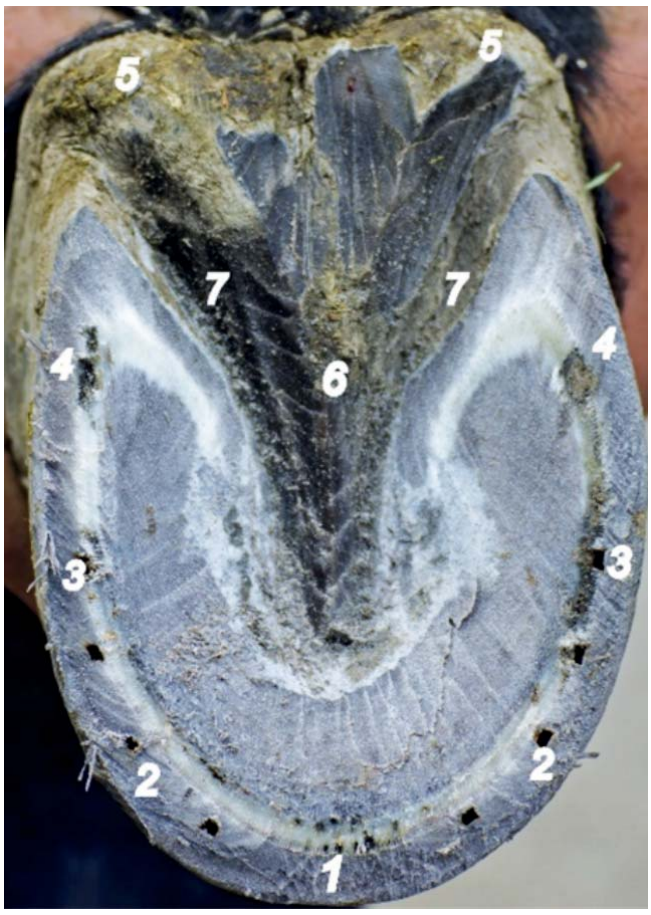


**Figure 2** - Solar surface of the mule hoof, left forelimb (1 toe, 2 medial and lateral toe quarters, 3 medial and lateral heel quarters, 4 palmar heels, 5 bulbs of the heels, 6 frog, 7 medial and lateral groove.

gitudinal diameter always exceeds the transverse one of 1/3, 1/4 or even 1/2 giving the appearance to the muline hoof of a quadrilateral[4]. It is a narrow hoof with a less rounded toe, a very large, concave and moist sole with more distinct horn tubules, a shorter frog, wider at the base and with narrower grooves and a more developed perioplic band[4].

The main function of the hoof is to support the weight of the animal (weight-bearing mechanism) and minimize the effects of concussion (anti-concussion mechanism) in the standing position and during locomotion[17]. The mule's hoof has an ideal structure to bear the weight and the pressures with respect to the size of the animal, the hardened terrain and the natural gaits. The hoof of this hybrid represents a perfect balance between strength/hardness of the hoof wall and extreme elasticity that together guarantee the remarkable safety during the stance phase of the mule's limb. This great elasticity in a rigid hoof wall is facilitated by the angulation of bony structures, the presence of the support ligaments, the bulbar portion of the digital cushion and the collateral cartilages of the distal phalanx, which extending more palmarly/plantarly, allow lateral movements for shock absorption[4]. Other structures improve the hoof shock absorption mechanism (heel expansions): particularly the frog portion of the digital cushion which is rich in fat, the tactile corpuscles, the sweat glands whose duct open into the central groove of the frog making it more elastic with their secretion, and the close interdigitation of epidermal and dermal laminae that presents an increasingly adhesion proceeding from the region of the toe to the heel quarters[4,8]. During the midstance phase under maximal loading of fetlock joint, it is possible to observe changes in the shape of the hoof that occur in different areas with diverse modalities and timing. The first variation is the outwards expansion of the heel quarters, followed by a narrowing of the coronary edge in front, then a reduction of the height of the hoof simultaneously with the sinking of the heels and finally a flattening and a sinking of the sole[7,17].

**Figure 3** - The master farrier Giovanni Carluccio's forge.

## THE BASICS OF FARRIERY

Farriery, synonymous with shoeing, is the science and art of applying a metal rim/bar or plate on the palmar/plantar surface (bearing or ground or solar side) of the hoof to provide protection and secure the sole. The single term "farriery" or "shoeing", however, comprises four very specific phases that require different skills and basic knowledge for excellent results: removing the shoe, trimming the hoof, forging the shoe and placement and application of the new shoe (real shoeing)[6,17,18,19]. Adequate hoof protection of horses, donkeys and mules used in agriculture, transport and army service is of fundamental importance for the greater wear imposed on this structure. In fact, the Ancient Greeks and the Romans used hipposandals, heavy iron horseshoes secured to the feet by cords or leather straps. It is possible to trace the birth of farriery to the Celts and Gauls who were known to nail-on iron shoes to horse's feet. Beside its practical and therapeutic implications, it immediately distinguished itself as a real art. The forge is the realm of the farrier, with a «siderotechnic» facility where the forging procedure takes place (Figure 3) and an open working area where to remove the shoe, trim the hoof and re-shoe the animal.

### Forging procedures: shoemaking

The forging process is the manufacturing of the shoe by hand after an initial assessment of the hoof conformation. The farrier chooses the most suitable bars, which in ancient times were made from waste material, such as chains of ships or cutouts of armor. The bars can be made of pure metal such as iron, steel, copper and aluminum or of their alloys. The best material is homogeneous, ductile, weldable and mild, like iron. However when iron is overheated becomes hard and not easily weldable. The type of cooling influences iron hardness: if spontaneous (air) the iron is softer, or if quenched in cold water it becomes harder. The bar is heated to the correct temperature with several heatings or firings that take place on a coal burning forge with the use of bellows; the shoe is forged with a hammer and held with tongs. With the first and second firings, the outside branch and then the slightly shorter inside one are bent. The same heatings will be used to start the lower nail hole openings, applying the stamp to the ground surface of the hot shoe and then to calibrate the upper nail openings with the hammer and back pritchel from the hoof or ground surface of the shoe. However, before the back pritchelling (back punching), after the stamp has been used it is desirable to remove the bottom piece of metal of each hole and fully penetrate the shoe with the pritchel on the ground surface of the shoe. In the mule since the hoof wall at quarters and heel is almost vertical the nail holes often are punched upright[17]. At the end of cooling, the shoe will be completed by rounding the edges with a few file passes. The farrier's skill can be evident from how many

**Figure 4** - Forelimb and hindlimb mule shoes.

times the hammer is used before and then the file to obtain an optimal quality shoe (Figure 4).

## Removing the shoe

To be reshod, the old shoe must be removed first before the novel shoeing. The initial step is to straightened or cut off the clenches with a buffer. Then the nail can be withdrawn with the use of a nail puller or placing the jaws of the pincer (shoe puller) between the shoe and the hoof starting at the heel, which is levered forward, toward the toe exposing the head of nail that can be grasped individually with the pincer.

## Trimming the hoof

Both for first shoeing and re-shoeing, the hoof must be trimmed before applying the shoe. To restore the proportions and physiological inclinations of the hoof, the wall, the sole and the frog will be trimmed with the intent to make the sole as parallel as possible to the solar surface of the distal phalanx (plane of pedal bone); therefore more hoof wall will be removed at the toe than quarters or heels, where the deformation occurs. During the hoof trimming the balance and hoof-pastern axis should be ideally maintained straight but this is not always possible in mules and donkey[20].
For a first rough trimming, the hoof cutter (hoof nipper) and toe knife are used. The irregularities of the palmar/plantar surface will be eliminated using a drawing knife and a hoof rasp. With the hot shoeing (hot fitting or hot setting) technique, the shoe is adjusted and fitted more accurately (Figure 5).

## Placement and application of the shoe: fitting and nailing on the shoe

The shoeing procedure is the first farriery practice for an animal that has never been shod before, while the re-shoeing procedure is the practice of removing the old shoe and applying a new one in a shod animal.
Choosing when to shoe young animals for the first time, the reduction of the normal lateral movements of the hoof wall at the heel and the blood circulation within the foot due to shoeing must be considered. Therefore it is advisable not to proceed with shoeing before 24 months of age. Sometimes in order to avoid excessive wear of the hoof capsule during the activity it is necessary to shoe a horse at a very early age for

**Figure 5** - Hot fitting.

working purposes. In these cases, to allow the lateral expansion of the heel, the farrier foresight will be to not put nails in the shoe behind the quarter of the hoof wall.
The re-shoeing interval time depends on both the shoes' extent of wear and individual hoof wall growth rate; the redundancy of one of these components commits to re-shoe the animal. Considering that the anticipation of re-shoeing damages the horny structures of the hoof due to excessive nailing, and the delay can modify the hoof conformation hindering heel expansion due to rigidity of the old horn, the re-shoeing procedure is usually performed every five to six weeks.
Depending on the method of fitting a hot or cold shoe on a levelled bearing surface of the hoof wall, shoeing can be executed with a hot or cold technique[4,6,17,18]. To fit correctly, a hot shoe is applied at red dull heat for sufficient time on a well-prepared bearing surface to ensure an absolute coaptation between shoe and hoof. For cold shoeing, a level shoe will fit adequately on a trimmed hoof with the help of measuring and balancing hoof tools, for example, a hoof gauge and the T-square. However the ability of the farrier lies in the capability to measure the hoof at a «glance». In any case a measurement of the hoof must also be performed in hot shoeing before forging the shoe.
Before shoeing an animal, the farrier must study the conformation of its feet and limbs, both standing squarely and in motion, observing the animal from the front, the side and behind to assess the correct alignment of the skeletal com-

ponents of the limb, the movement and the placement of the hoof as it strikes the ground both at rest and at different gaits. After hoof trimming and forging the shoe, the latter must be placed on the hoof bearing surface to evaluate the exact adherence between the two surfaces (surface fitting), and the adaptation of the external edge of the shoe to the perimeter of the hoof wall (outline fitting: close or wide)[4,17,19]. The shoe must be steady by pressing alternately from one side or the other, the heel of the shoe should extend correctly behind the bearing surface and the branches of the shoe must be equidistant from the central groove of the frog. The shoe must be placed on the solar surface of the hoof with congruency between the shoe's and the hoof's toe, and the frog lying centrally between the two heels of the shoe. Subsequently with the shoe held in this fitted position, the nails are driven, the first nail at the outside toe quarter and then at the inside. When the hoof and shoe outline edges correspond, the remaining nails are driven alternately on each side of the heel quarters and finally on the toe, otherwise the farrier moves the shoe in the correct position with light hammer blows on the left or right branch. Once the nail is driven, the most important act is to immediately bend the tip exiting the hoof wall approximately 2 cm above the junction of the shoe and the hoof; then the turned over nails ends must be cut off and bent into the small indentations of the hoof wall horn created with the gouge (clench trenching process) into which the clenches can be sunk (clenching process).

The farrier's ability will also have a cosmetic result: the clench line should be straight and parallel to the ground or to the coronet (Figure 6) otherwise the clench line will «make music».

Finally, the irregularities of the solar edge of the hoof in contact with the shoe are smoothed with the file side of the rasp.

## MULE-SHOEING

In ancient times the small dimension of the mule's hoof was considered insufficient to support the work, so the shoeing provided shoes larger than the hoof, to give more stable shoeing and ground contact. It was also believed that this practice promoted the impulse of movement.

Over time it has been noted that the dimensions and the structural characteristics of the muline hoof were optimal for the work that required walking steep and rocky paths between hills and mountains. However, the use of a good coverage (wide-webbed shoes) has been preserved to increase the duration of the shoeing and to facilitate the passage on soft soils where the animal could easily sink with hooves with a reduced bearing surface and a notably concave sole.

It is important to consider whether the intended use of the mule is for ordinary service or heavy draft. For the latter, shoes fitted wider than the hoof on the toe and heel, were used to increase the ground contact and promoting efficient impulse while preventing slipping[3,4,21]. The mule's shoes display a web of greater and uniform thickness over their entire extension compared to those of horses.

The toe of the front shoe is rounded, fitted slightly wider and turned up ("set toe"); its outline fitting is marginally wide on the toe and on the external branch[3,4,21]. The front shoe coverage, therefore, is slightly wider at the toe, and gently decreases to the toe quarters, heel quarters and heels; moreover the internal branch is narrower than the outside[4]. The front shoe must cover the heels and never extend behind them. The choice of making a shoe with calkins is at the discretion of the farrier. The nail holes, from six to eight, are placed and angled away from the outer edge (coarse holing) and are designed to use nails with short wide shanks.

The hind shoe shows the same characteristics of front shoe and some distinct properties; such as a larger blunt toe ("square toe"), equal full outline fitting proportions, and identical branches coverage[3,4,21]; the nail holes are stamped more towards the heels to not impair the toe, and the calkins are always fixed.

In mules, to achieve the best surface fitting between the shoe and hoof wall, the hot shoeing technique is preferred. Three main types of shoe have been identified and designed to adapt shoeing to the different uses of the mule: the "square shoe" with a blunt shape of the toe ("square-toe-shoe") suitable for draft mules, the "round shoe" with a wide round toe bent up ("rocker-toe-shoe") for mules used in agriculture, and finally the "Florentine shoe" for pack mules used in the Maritime Alps and the Genoese Apennines. The latter shoe is heavy and difficult to hand forge[3,4,21].

Sometimes in winter, the use of a shoe with an additional nail hole may be preferred for the eventual insertion of a non-slip nail. To help the leakage of water between the shoe and the sole, some farriers make a notch at the toe on the palmar/plantar edge of the hoof; other farriers prefer to forge shoes with a web narrow on the heels compared to the rest of the branches and bend-up behind the heels to protect them and avoid excessive grip causing injuries to the hoof and increased risk of a lost shoe[3,4].

In the military field, for the mules used in mountain artillery, in the Alpine's Infantry and in Bersaglieri Regiments and other military districts, the same indications of shoeing the mules for civil service have also been adopted, applying the calkins both on the hind and the front shoes, and using the same shoeing method regardless the type of use for which each mule was enrolled in the army.

In the practice of modern mule shoeing, the methods for protecting the hoof capsule with nails or adhesives are similar to that of the horse. The shoe may be made of metal (steel, aluminum and titanium), synthetic polymers, or various composites of the two materials[22]. Typically, each mule shoe must be hand-forged or machine-made horseshoes

**Figure 6** - Clench line at finishing off.

must be customized. However, in some countries, shoes specific for mules are manufactured in different sizes (“Mule” and “Mule Heel”, St. Croix Forge, USA; “Ferro da mulo ramponato”, Viali, Blacksmith, IT).

## CONCLUSIONS

This review based on scarce scientific evidence obtainable in the veterinary literature provides an overview on functional anatomy of muline hoof and mule-shoeing techniques. Furthermore the principles of farriery are discussed in its basic traits. This mule-specific knowledge is critical for equine practitioner and professional farrier as it has an important impact on the health and welfare of the animal.

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