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Understanding Laminitis: How We View "Normal" Function

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CHANGES THAT ARE VIEWED AS NORMAL CAN COMPROMISE THE FOOT

Our horses are living longer and we'd like them not to fail. With each year, we have compiled more and more data to show how the equine foot functions, and how the foot responds to what practitioners do. Every time we touch the foot, the internal structures change. When we do a better job recognizing and questioning what is considered "normal", we help the horse to avoid the consequences of laminitis, or to better survive the rehabilitation from laminitis. The concepts explored here can help in recognizing critical areas early on, at any point in the life of the horse, so that they may be addressed.

THE FIRST STEP: WHEN ARE ADAPTIVE CHANGES A PATHOLOGY?

The definition of pathology in medicine is the study of disease. It is also defined as something *abnormal*. The onset of clinical signs indicates that structural and/or physiological changes have occurred and have progressed to the point beyond where the horse can compensate for these changes and the body can no longer support itself normally.

Here's an example: A horse is off in the front distal limbs. Professionals evaluate him via lameness exam and radiographs. Finding none of the usual boney changes within the navicular bone, it is concluded that the horse does not have navicular syndrome. Six months later the horse is still off and now radiographs reveal changes at the navicular bone. The horse is now diagnosed with navicular syndrome.

> **PATHOLOGY**
> plural pathologies
> 1 : the study of the essential nature of diseases and especially of the structural and functional changes produced by them.
> 2 : something abnormal:
>   a : the structural and functional deviations from the normal that constitute disease or characterize a particular disease
>   • the *pathology* of pneumonia
> https://www.merriam-webster.com/dictionary/pathology

The initial internal foot changes causing the lameness were mainly "soft tissue stresses" within the foot, but they were not recognizable with x-rays. Bone changes had not as yet become fully evident, as it usually takes many weeks and months for these changes to be detected via radiographs. This *lack of recognition of soft tissue stresses postpones diagnosis at a critical juncture* where the horse may have been helped more quickly.

The same analogy may be used for laminitis. Many husbandry and shoeing/trimming practices set the horse up for gradual, constant, and progressive changes, which in turn begin to set the horse up for potential catastrophe during an initial bout of laminitis.

The good news is that once we can recognize these initial adaptive changes in the soft tissues and bone, we can recognize much earlier the potential for harm.

In the case of navicular syndrome we don't have to wait for the appearance of bone changes to diagnose caudal heal pain (navicular syndrome) to do beneficial service to the horse. We can begin to trim the foot such that more support occurs via the solar surface of the foot rather than the wall to reduce the impact of vibrations. We can also recognize the early adaptive changes in the foot that gradually reduce or remove the supportive and protective tissues within the foot, which normally help the horse deal with the early initial signs of foot soreness or laminitis.

By removing or weakening these supportive and protective mechanisms within the foot's tissues, the foot and other body areas are no longer able to support the horse in stance and movement during the initial phases of the laminitic processes. As a result, the foot has gradually changed negatively with the initial onset of laminitis. Recognizing structural and functional changes earlier will help the horse avoid the consequences of these events.

CONCEPTS THAT CAN HELP AT ANY POINT IN THE LIFE OF THE HORSE

The foot is very responsive and adaptable. Mother nature is going to balance the internal structures of the foot on whatever you put on the ground — the wall, the sole or a combination of the two. If you load the horse on the hoof wall, that will become the primary loading structure and the coffin bone will be suspended inside the hoof.[1,2]

When the sole is loaded preferentially, less load will be on the wall and, hence, less suspension; greater amounts of load will be on the solar structures. This latter condition provides a greater support surface than with the hoof wall alone. An appropriate analogy to loading the hoof wall may be someone in high heels — a smaller surface area. With greater load on the solar structures, a larger surface of support is achieved, perhaps analogous to a sneaker. In biomechanical terms this simply means a load is distributed over its surface of support: a large surface area of support (e.g., sneaker) means smaller loads are placed on each unit of surface area for support; conversely, the same load on a smaller surface area (e.g., high heels) means that greater loads are placed on each unit of support.

As the weight of the horse or load will be the same in these two instances, the **smaller surface area results in higher stresses being placed upon the internal foot tissues. A larger surface area on the ground during loading lowers stresses that are placed upon these very same tissues.** The functioning of the foot in the latter situation will remain in a healthier state for a longer time period.

This is evident in how the foot responds when changing loading structure, as we can see the changes grossly. We have found long-term effects of peripheral loading of the foot to include the following:

1. The foot becomes *asymmetrical.* Steep versus flared sides are accepted as normal in greater than 90% of equine feet. We are all used to hearing and seeing this axiom; however, most asymmetry is an environmental factor due to trimming practices that distort ***equilibrium*** in the foot. It is difficult to distribute the load evenly around the perimeter of the hoof wall.
2. *Bone is lost* from distal parts of the coffin bone, creating the potential for pedal osteitis, crushed toes in laminitis, and an increase in biomechanical issues.
3. The *long toe* becomes a common occurrence, altering the vasculature within the solar dermis, decreasing energy dissipation and support, creating biomechanical issues involving the deep digital flexor tendon (DDFT), decline in frog, tendon, and ligament health, as well as issues further up the leg.
4. *Vascular perfusion* is altered creating extreme detriment to foot function: energy dissipation and support.

A suspended coffin bone, asymmetry, long toe, and altered vascular perfusion, will cause bone loss primarily in the distal end of the coffin bone and on the flared side of the foot. When the laminae connection is lost due to laminitis, the suspended boney column sinks or rotates. If the horse has lost significant bone, this bone can no longer support the horse's weight, as it has become osteoporotic in its distal parts; hence, the coffin bone cannot support the horse's weight and the toe becomes crushed.[3]

Conversely, in a solar-supported foot, less bone will be lost in the distal parts of the coffin bone. Because bone is also deposited, a denser coffin bone will result, with better support of the weight of the horse and better ability to withstand laminitis events. NOTE: the dermis of the solar areas will be healthier and will provide better support as well. Loading the sole, promoting foot symmetry and shorter toes, helps a coffin bone to avoid osteoporosis, bone fracture, and the loss and disruption of the vasculature of the foot's dermal structures so often seen today in laminitis.

Below are areas where we believe recognition of early pathology will help keep the horse safer during a laminitic event.

SUSPENSION

We have written extensively on our reasoning that the hoof wall load should range only between 5 - 20%.[4] With a shoe or extended hoof wall, the load increases towards 80 - 100% on the hoof wall on most firm to hard surfaces. As a result, impact energies enter the hoof wall and pass up the wall into the dorsal wall through the more proximal foot. While these impact energies are reduced or "dissipated" as they pass through the hard-keratinized wall to the soft dermal tissues (epidermal-dermal interface of the laminae) the wall and soft dermal tissues are not designed to dissipate energy impact forces and remove them from the horse's foot. Impact energies affect the soft epidermal laminar tissues as well as the dermal vasculature, which are referred to as the suspensory apparatus of the inner hoof wall.

This dorsal hoof wall/dermal tissue route passes through the "suspensory apparatus" but by-passes the specialized energy-dissipation mechanisms of the caudal foot that should be doing this work.[5]

Figure 1. The tissues within these two feet respond to energy stresses differently. *Foot A (L)* has a coffin bone suspended from the hoof wall. *In Foot B (R)*, the coffin bone is supported from the sole.

When the foot is loaded primarily from a solar surface (Figure 1), the energy absorptive tissues of the frog and lateral cartilages will actively dissipate impact energies, and lay down more bone in the solar cortex of the coffin bone and at insertions of the DDFT and the impar ligament. This will benefit the horse in the long term. The dirt plug supports the frog function without the constant pressure of pads or composite material. Through the use of a dirt plug, which completely loads the solar surface of the foot, the back part of the foot will respond in a positive way to support the horse.

These variable effects — positive or negative responses — are due to the total surface area of contact. A small surface area will create high pressure from energy dissipation within the foot. A large surface area will create low pressures and stresses within the foot.

Through observation of cadaver feet, MRI, and histological studies, we have seen that when the solar surface is primarily loaded, with minimal — or at the very least reduced — load on the wall, bone is laid down in the bottom half of the coffin bone. These findings are critical. A "normal" coffin bone is considered to have most of the load of the top half of the coffin bone. These "normal" bones are shod horses or barefoot horses with a long wall.

If you stood on a foot (Figure 2, left) on a hard surface — where the hoof wall is beyond the sole – the weight will be suspended through the coffin bone. A foot loaded through the sole (Figure 2, right) will result in less suspension from the wall and more support through the sole. As further described in the drawing at right, the tissues inside the foot will respond differently to the energy impact depending upon how the hoof is set up.

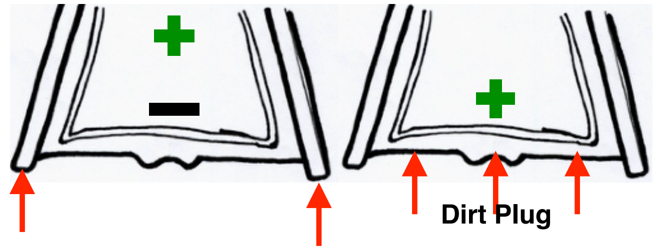

Figure 2. Bone is most dense at the top half of the peripherally loaded coffin bone (plus sign) and less dense at the lower half (minus sign). When the solar surface is loaded via dirt plug, bone is more dense in the lower half of the foot (plus sign).

In studies working with engineers using *finite element model analyses*, a hoof section being loaded on the wall versus the same one being loaded along the sole revealed different results with regard to bone support. We concluded that when the wall was loaded, the dorsal half of the coffin bone had more bone laid down, while the bottom half had bone minerals lost. Conversely, when the sole was preferentially loaded, bone was deposited or at least was not lost in distal areas of the coffin bone. In the bottom half, bone is lost. This is crucial to our understanding of "normal".

ASYMMETRY

Figure 3. The affect of environmental influence on a three-year-old foot, which creates steep versus flared asymmetry in 90 % of horses.

Asymmetry leads to uneven response within the foot with tissues on one side being loaded differently than those on the opposite side.

It is estimated that 90% of horses are steep and flared. (Figure 3) While everything in nature is asymmetrical to a small degree, the obvious amount of asymmetry is a big deal, as one side is loaded more than the opposite side of the foot and each side adapts differently. It becomes an ongoing cycle. Today gross asymmetry is viewed as normal.

In most coffin bones, the flared side is on the lateral side of the foot. (Figure 4) The bone on the flared side will be thinner than the steep side of the foot. On the steep side the cortex and trabeculae bone are thicker, but also thinner on the flared side. (Figure 5) These flared and steep areas within in the bone indicate that the bones and other tissues are continuously adapting to the weight bearing loads being placed upon the foot and limb. These conditions set the horse up for potential problems when laminitis occurs, as the thin cortical areas cannot support the horse's weight, especially when suspension of the coffin bone is damaged or destroyed by laminitis.

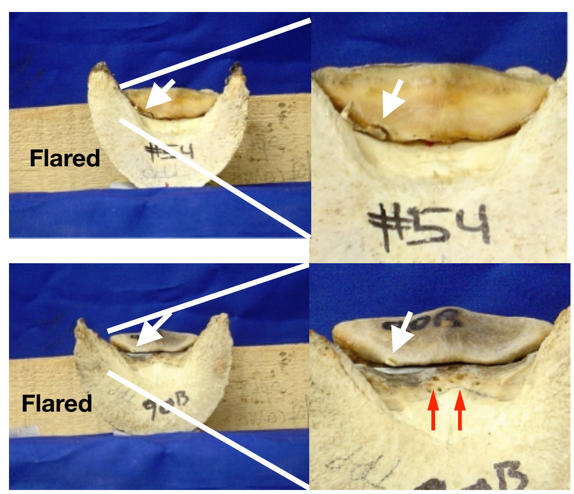

Figure 4. Stress bumps and chip fractures in the flared side of the above feet are related to conformation of the distal phalanx and hoof and may be early indication that increased stress is present in "bad footed" horses.

We have shown in early work[6] that most horses are not born with any gross asymmetry of the distal limb. We have reviewed hundreds to thousands of coffin bones, and while they are generally similar, they are different as each bone has been sculpted by the horse's environment. We have seen that even the coffin bones of 3-year-old race horses are not only growing but are also already remodeling (or being sculpted) to the loads. They are losing bone on the as above-mentioned flared side and often near sites where the nails and clips are positioned when they are shod. Conversely, they are depositing bone or at least losing less bone in other areas. Coffin bones with more symmetry have much more internal bone support throughout the foot with less bone loss in specific areas.

Normal flexor cortex

Elongated flexor cortex

Figure 5. Elongated flexor cortex, found on the flared side, may be precursor to chip fractures.

The asymmetry we normally see is not a genetic trait, but more of an environmental problem. The farrier/ trimmer is one of the biggest environmental factors that can affect the hoof and the foot. While some outliers are possible, we believe most occurrences can be addressed, restoring a more symmetrical foot.

Modern professional literature has many different ways to fix asymmetry, from doing nothing, to shoes, to foot mapping, to body work, to trim, etc. The way we trim these horses has the greatest impact on asymmetrical feet. When you start loading one side of the foot preferentially to the other side, you begin a vicious cycle that affects P3, P2, the navicular bone, and tissues in the foot, leg, and body.

We have found that, over time, if you simply trim the foot to load the sole preferentially, and bring the toe back, the foot will **equilibrate** around that the central loading area of the foot.

THE ARCH

In the natural arch, the strongest supports are on the ground. The concavity, the natural arch in the equine foot, is and should be a strong structure. As we have seen in hundreds and hundreds of coffin bones, this notion is correct until humans get involved in the husbandry of the horse. We do things that promote less healthy feet, rather than the opposite to promote strong feet.

In the horse the densest, strongest region is the arch where the deep digital flexor tendon (DDFT) and the impar ligament attach. This dense bone should continue to the peripheral aspects of the coffin. The edges of the bone should be thick and strong, which they are when the young horse is growing up. However, when we load the foot peripherally, bone is lost not only peripherally, but also through the arch of the coffin bone.

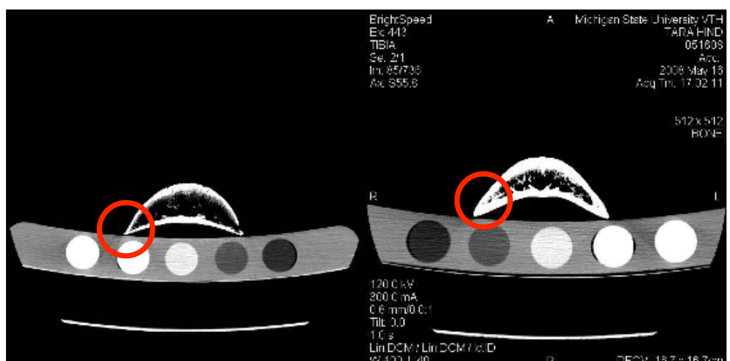

Figure 6. The CT scans above show two bones with a history of different loading. A peripherally loaded bone (left) is less dense, while the solar-loaded bone (right) is more dense.

A shod horse (Figure 6, left) with thin distal edges, will crush the distal ends of P3 during boney rotation or descent in a laminitic event. They cannot support the weight.

The barefoot horse (Figure 6, right) has decent density all around the coffin bone, most importantly at the distal edge on the ground. He will have a better structure for withstanding a laminitic event.

Can we see evidence of distal erosion of the coffin bone and correct it? Yes. Evidence of this process — the erosion of P3 — can be seen early on via radiographs and the use of a simple plastic ruler, described below.

ADHESIONS

Adhesions can be seen in laminitic and navicular horses (Figure 7). Very large humans often need their knees replaced as the pressure of the weight is squeezing the fluid out of the articular cartilage of the knee joint. Eventually an adhesion between the DDFT and the navicular will form. These horses should move as much as possible, at their will. Do not keep them stall bound.

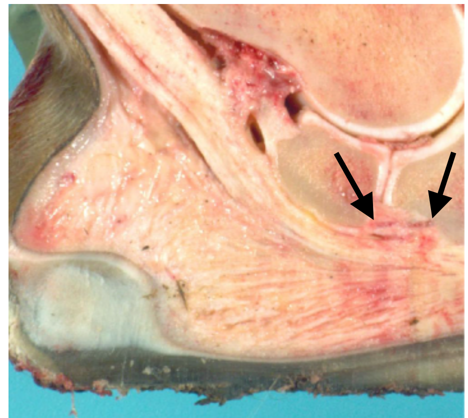

Figure 7. Arrows point to adhesions in laminitic and navicular horses, evidence of early deterioration.

THE SLIPPER TOE

What is often described as a “slipper toe” due to elongated toes can really be a fracture of the dorsal cortex and solar bone at P3 (Figure 8) in the “non-normal” (i.e., diseased) foot. Peripheral loading has changed the bone distribution and density of the bone content. Horses with this type of bone will have a much harder time withstanding laminitic events.

With the onset of laminitis and collapse of boney attachments, the weight is not supported by the distal parts of the coffin bone. The distal end of P3 is fractured with one-quarter to one-third of the coffin bone crushed as a result. When bone breaks off, the horse suffers with this fracture like that seen in pedal osteitis.

Figure 8. With laminitis and the collapse of bone attachments, weight is not supported by the distal parts of the the coffin bone, resulting in the crushing of the bone.

Fractures are less likely to happen when the coffin bone is dense along the perimeter of the coffin bone.

If thinning cortex is recognized earlier — which will also indicate thin trabeculae — steps can be taken to avoid crushed bone in laminitis. With the use of a plastic ruler, one can see the bulge in the dorsal cortex of P3. (Figure 9) The bone edges should be smooth and rounded; when they are fuzzy in appearance there is bone remodeling along the dorsal edge as well as at the tip of P3: this means that the bone is thinning and beginning to become osteoporotic. Addressing this now through trimming to change the load will help this horse return to a denser P3.

When the long toe, loading, and asymmetry issues are addressed through the trim, the slipper toe remodels such that it disappears in 1 - 2 years.

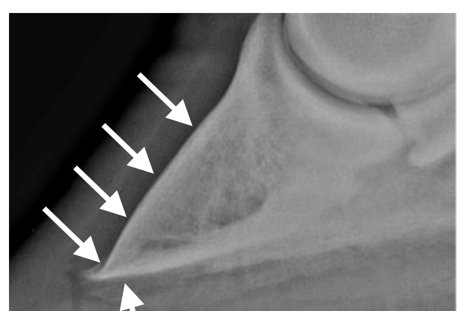

Figure 9. A bulge in the dorsal cortex, fuzzy edges of bone and remodeling on the dorsal edge are evidences of bone deterioration.

LONG TOE, UNDERRUN HEELS, THE FROG AND CENTRAL SULCUS

Long toe is a common occurrence and is also considered normal, often assumed to be genetic, and difficult to correct. As an example, there is nothing wrong with the Thoroughbred foot that a good frequent trim cannot help and correct. By trimming the toe back, and bringing the heels back as well, you can regain and maintain the use of the internal structures as they were meant to function.[7]

Feet we see typically have a long and thin central sulcus, which means the frog is not working. The frog gets bigger when you don't touch it.

Figure 10. A dip along the coronet in the heel region of the caudal foot indicates the foot is underrun and the central sulcus is not on the ground.

Most literature and hoof professionals describe the best foot as having half of the foot in front of articulation and half behind this point of reference. We have worked successfully with a larger area (60%) behind articulation and smaller area (40%) in front, meaning that the frog can regrow and return to its functional state. We believe that this ratio should be a goal to strive for when trimming the foot.

Additionally, a dip along the coronet in the heel region of the caudal foot (Figure 10) indicates the foot is underrun and the central sulcus is not on the ground, further inhibiting the function of the frog. When you see the coronet band start to curve down, it means the central sulcus is not entirely on the ground. Boney column support is not optimal, and as the frog has less and less function, successively less negative pressure takes place inside the foot. The foot of such a horse may be sound (i.e., not lame) but it does not mean that the foot is functioning at its maximal efficiency to support and remove any or most impact energies.

When we encourage a shorter toe, the frog's surface area and volume increase. The frog and its internal structures adapt and respond with increased ligament and microvessel support for the boney column and tissues, as well as energy dissipation.

However we have also observed that in a barefoot horse, the circumflex artery is 4 - 5 mm beyond (outside) the rim of the coffin bone. The sole dermis is thicker in a barefoot horse. Thick corium with lots of proteoglycans and microvessels contribute to the cushion under the coffin bone. A healthy foot has a very thick layer of proteoglycans and other proteins concentrated in the dermis between the coffin bone and the sole to create a "gel plug".

SUMMARY

If the helmsman of the Titanic had been paying attention to the ice under the water, there might not have been an accident.

Approaching the foot from a neurobiological point of view, we realize the anatomic assumptions in current literature are not quite right. Once understood, it can change your viewpoint and approach. A lot of what we do to the foot in every day husbandry is decreasing the ability to withstand laminitis and other problems. Often internal foot deterioration is not realized until gross clinical signs are recognized, while all along, the foot has been gradually deteriorating. Under these conditions when laminitis strikes, the horse has a more difficult time to withstand the event.

When you appreciate that changes in the foot can be seen much earlier, even in horses that are still clinically sound, you can start to treat the issue and head off catastrophic failure. You don't have to wait for change in the navicular bone or for P3 rotation or descent. There are areas that will speak to you long before those things occur. Addressing those issues early serves the long-term health of the horse.

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All photos Robert Bowker files.