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The Vascular Cushion of the Frog: What Does it Do? (2015)

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Most research has focused upon the hoof wall as being the primary loading structure and, as a result, much of our research emphasis, veterinary treatments, and husbandry practices and protocols have been directed towards the hoof wall in both health and disease.

Several studies[1] have focused upon the circumflex artery as one of the main arterial blood supplies to the hoof wall: this artery courses around the perimeter of the coffin bone with numerous smaller branches supplying the dermis between the epidermal laminae. It does not, however, provide the major avenue of blood flow to the tissues of the foot.

There are several major arterial branches that supply other areas of the foot. These branches all come together to provide a vascular network through the palmar foot. It should be noted that this extensive blood flow provides very little nutritional benefit, as the tissues within the back part of the foot have little need of the nutritional function of blood flow. Contrary to popular dogma, most of the blood flow to the foot serves other functions besides nutrition and oxygenation to the tissues. Two of these other functions include support of the boney column and dissipation of vibrational energy.

The vasculature in the rear of the foot is quite small but vast, as exemplified by an inordinately massive number of small vessels. This network of small vessels serves a unique purpose. It is capable of supporting the loads of the horse, due to its extensive network of parallel microvessels, and is also capable of simultaneously dissipating energy. In other words, the small size of these vessels provides a method to reduce the vibrational energy generated during the foot-ground impact; larger vessels will not reduce the vibrational energies as the forward fluid flow through them does not encounter much resistance.

BLOOD FLOW AND THE LIVE ANIMAL

Previous work has stated that when the horse was standing, there was hardly any blood in the foot with all blood going to the hoof wall. However, this work was done on dead horse feet, not taking into consideration the contribution of the nerves of a live animal.

To evaluate how a living animal influences findings, tissue perfusion was measured with Doppler ultrasound on horses standing on various surfaces. Blood flow was measured at the level of the fetlock with the foot doubly loaded by raising the opposite foot on a cement block. Blood flow was nearly stopped in many feet when measured at the fetlock. With the same horse on a cement block, placing a simple wash cloth under the foot allowed blood flow to return dramatically to nearly normal.

See: Bowker, RM, *NERVES, NERVES, NERVES: WHY are THEY SO IMPORTANT to the HORSE?* (2013) ecirhorse.org

The vessels are between 4 - 100 microns in the lumen diameter and are too small to normally visualize with most clinical — and with some anatomical — techniques. In order to visualize vessels within the body with radiographic techniques, vessels need to be greater than 700 - 900 microns.[2]

In summary, microvessels exist mainly for:

1. **<u>support of the bony column</u>**: similar to that of a pneumatic tire that supports your vehicle. Picture a canvas tire. The fascia and fibrocartilage form the outside "tire" and small parallel microvessels are the air filled "inner tube"; and

2. **<u>dissipating energy</u>**: this unique arrangement of fascia, fibrocartilage, and small parallel microvessels enables the foot to perform critical energy dissipation when the foot hits the ground, while simultaneously supporting the horse. Few natural structures can do both functions of support and energy dissipation as efficiently as the frog and digital cushion within the horse's foot *and* perform these two functions simultaneously.

To expand from Poiseuille's law, we know that to keep the same volume of blood flow entering the foot as that exiting the foot, several things must be present, and they must all function efficiently:

1. If the vessels are going to be smaller in size, there have to be many more vessels present. The cross-sectional area that carries the blood through the foot must be of a similar or larger size. Again, these vessels have to be very small. Large vessels do NOT dissipate energy and, in terms of the biophysical properties, large vessels are not capable of supporting such high loads.

   Furthermore, these small vessels or microvessels should be specialized and not merely capillaries for transporting nutrients and oxygen to the tissues. The microvessels within the frog are, in fact, unique, as they are structurally not capillaries.

2. The <u>total resistance</u> to forward flow through all of these microvessels through the back part of the foot will be less. However, through an individual microvessel the resistance will be high. Common sense would indicate that forcing fluid through small-caliber tubes (i.e., like "swizzle sticks") requires energy, which is produced when the foot hits the ground. This energy to force fluid forward actually resists or slows down the blood flow through these microvessels, thereby dissipating or absorbing the energy created during the foot's impaction with the ground. However, due to the enormous numbers of these microvessels that are also parallel to each other, the total or overall resistance to forward flow of blood through these foot tissues becomes less and less; the total resistance can theoretically approach zero.

   The INDIVIDUAL resistance to forward flow of blood through each of these smaller vessel is, however, significantly greater, similar to electrical current in a parallel circuit where total resistance to electric flow is less than if the current was passing through electrical wire in a series circuit.

BRINGING POISEUILLE'S LAW HOME

While the above two events may sound counter intuitive, we use them every spring when we plant and water our gardens.

Let's say we want a lot of water to get to each of the rapidly growing plants, but we do not want the flow to be so great that it erodes all of the topsoil away along with, eventually, our plants. So we arrange to have some sort of sprinkler system that permits a lot of water to get to the edge of the garden (i.e., large flow or amount of water through a large-caliber hose); then we hook the large hose up to numerous small "micro-hoses" or "trickle flow tubes" or sprinklers to slow down the force of the water, thereby increasing resistance to forward flow. This configuration allows lots of water to get to the garden without washing everything away.

This is exactly what happens in the back of the foot of the horse: (1) a large amount of fluid (blood) passes to and through the frog with little or zero TOTAL resistance; (2) the microvessels — with increased INDIVIDUAL resistance — dissipate or reduce the flow. The more energy dissipated, the healthier the foot tissues become.

When the vibrational energy due to impact is *not reduced,* it starts to affect blood flow and to produce *degeneration and pathology* within the foot tissues.[3] These are the facts regarding the mathematics and biophysics of fluid flow.

In human research, this is what occurs in carpal tunnel syndrome and in construction workers using jack hammers.[4,5] In the rat model of this research, when a tail is subjected to 15 seconds of vibration at 250 - 400 Hz, the arterial vessels are directly affected by the vibrational energy and they remain constricted for three days via the vibrational actions on the receptors on the vessels[6]. Research from Europe has shown that when peripheral loading devices are used, they create vibration at a rate of 2,000 to 3,000 Hz.[7] Over long periods of time the arterial constriction begins to have other, deleterious effects on nearby tissues. The connective tissues begin to become deficient in their supply of oxygen and nutrients to sustain and support these surrounding connective tissues.

THE NAVICULAR SYNDROME CONNECTION

We have previously shown that in navicular horses, many areas of the foot are affected[8], not just the navicular bone. The damage created by the generated vibrational energies of the foot impacting the ground are not specific or restricted to the navicular bone. Historically, navicular syndrome was diagnosed primarily from the damage observed at necropsy, after the disease had been ongoing for an extended period or was in its final stages. The pathology from poorly dissipated vibrational energy had begun in surrounding tissues long before it impacted the navicular bone.

For example, the lateral cartilage in the caudal third of the foot is significantly smaller; the microvessels to the navicular apparatus and their substance P receptors are damaged and reduced in number; the bone density within the coffin bone of these horses with Navicular Syndrome is a third less dense than the coffin bones of other, non-pathological horses between the ages of 2 and 31 years of age! Researchers have said that the distal annular ligament is fused to the Deep Digital Flexor Tendon (DDFT). (Unpublished) This is actually pathology. There are blood vessels in the distal annual ligament that, when damaged due to vibration, will cause the ligament to fuse the the DDFT. Healthy vessels there help support the navicular apparatus.

These observations indicate that navicular syndrome effects are NOT SPECIFIC TO THE NAVICULAR APPARATUS but rather affect the entire foot. Few researchers have investigated areas beyond the navicular apparatus so it has not been reported — except by our laboratory, where it has been shown that vibrational energy passing through the hoof wall does NOT dissipate within the hoof wall and continues through the other foot and pastern tissues.

FASCIA IN THE FROG AND THEIR MICROVESSELS

Nearly 80 years ago, researchers found several ligaments in the frog.[9] Current research never talks about them, but we will explain their significance. It is known that both lateral cartilage and the fascia form support structures of the frog and digital cushion. However, no one has looked under the microscope to see that there were also millions of microvessels.

Chondropulvinale ligaments (CPL) and *condrocompedoungulare* (CPU) are but two groups of these fascial sheets and ligaments through the frog, digital cushion and pastern, that support the caudal foot. CPL means “Cartilage to swollen” part of the foot. CPU means “cartilage with foot nail”[10] (Figure 1)

These, and many other fascial sheets attach to lateral cartilage, frog stay epidermis, over the caudal foot and the pastern and, more proximally, to the Proximal Phalanx (P1). When the foot is on the ground these fascial sheets, along with blood flow through microvessels, aid in support of the digit as the back part of the foot expands, creating a negative pressure and causing an increase in blood flow.

In between sheets of fascia is an enormous sheet of vasculature under 1 mm in diameter that cannot be seen by standard radiographic techniques. These vessels, along with the ligaments, support the horse, holding him or her up much like a pneumatic tire as we have mentioned above. (Figure 2) As noted, this arrangement results in an "outer canvas tire" and an "inner tube" filled with vasculature that is capable of supporting the horse's bony column when loaded.

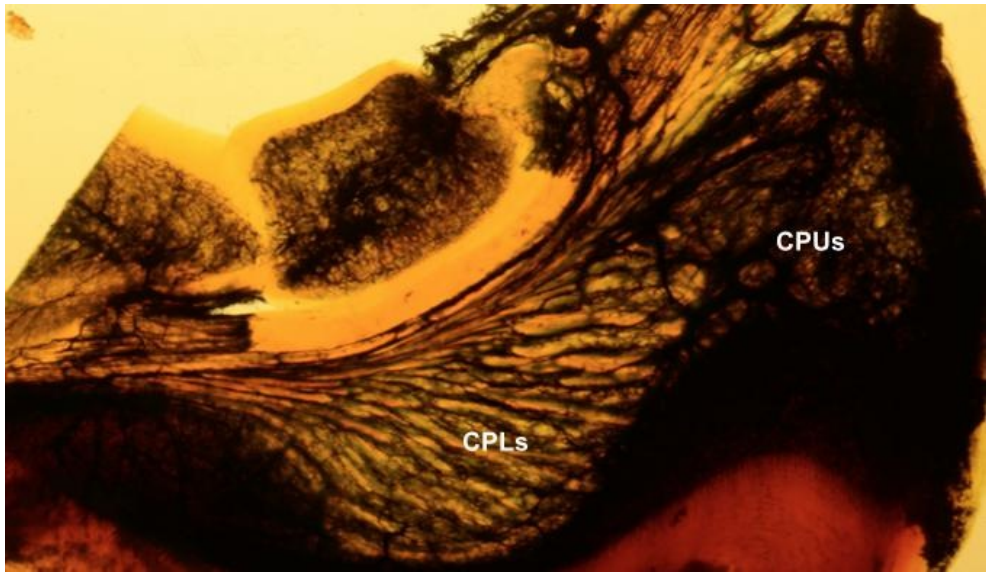

Figure 1. Section showing extensive microvessels through cuneate frog between the ligaments of CPL and CPU. The vessels are filled with India ink, a small particle that can fill vessels less than a few microns in luminal diameter.

REVIEW

All of the large vessels allow a lot of blood into the foot before it hits ground. As the foot hits the ground, blood is forced into smaller vessels. Energy required to force fluid through these smallest vessels is derived from impact.

In every-day living, this is similar to getting toothpaste out of a tube, as one's fingers supply energy to squeeze the toothpaste out.

Energy causing forward flow is gradually reduced or "absorbed" as the forward flow overcomes friction of the fluid along the vessel walls, moves against the red blood cells, and negotiates the viscosity of the fluid. As the energy is gradually expended, or used up (normally called "work"), it pushes the fluid through the vessels; thus, less vibrational energy produced during foot impact remains to pass to the connective tissues of the foot. In other words, the energy is absorbed during this work.

Blood is squeezed through these microvessels, leaving the foot and traveling to the pastern and fetlock joints. When the foot comes off the ground the larger vessels allow new blood to enter the foot and refill the just-evacuated vessels before the next foot fall, when the cycle repeats.

The process of forcing fluids through these vessels of high resistance is what dissipates or absorbs the impact energies. In addition, it provides support of the horse through the vasculature surrounded by the CPL and CPU ligaments, creating a "pneumatic tire-like" configuration within the cuneate frog. The veins within the equine foot and distal limb pulsate, which moves blood up the leg and returns blood back the heart.

WORK (Physics) -"*When a force acts upon an object to cause a displacement of the object, it is said that work was done upon the object. There are three key ingredients to work - force, displacement, and cause. In order for a force to qualify as having done work on an object, there must be a displacement and the force must cause the displacement. There are several good examples of work that can be observed in everyday life - a horse pulling a plow through the field, a father pushing a grocery cart down the aisle of a grocery store, a freshman lifting a backpack full of books upon her shoulder, a weightlifter lifting a barbell above his head, an Olympian launching the shot-put, etc. In each case described here there is a force exerted upon an object to cause that object to be displaced.*"

http://www.physicsclassroom.com/

In this case "work" was done by the friction absorbing the forward flow of energy, which in turn reduced the amount of vibrational energy.

CPLs and CPUs are like parachute strings connected to the wall of the frog. When the foot is on the ground with P1 and P2 straight, the frog volume increases or expands due to engagement of the CPL and CPU ligaments. Many more vessels opening up and filling begin to dissipate energy and support the weight of the horse.

The fascia will become damaged before signs of Navicular Syndrome occur. Initial degeneration in the frog occurs three to five years before radiographic and clinical signs of lameness occur. In Navicular Syndrome, blood vessels and ligaments sustaining damage can be seen long before what is typically recognized as "navicular" changes. (Unpublished)

Vessels in the frog between these fascial sheets, lateral cartilage, and digital cushion are 4 - 100 microns in luminal diameter. While they need a little bit, cartilage ligaments and myxoid tissue don't require lots of nutrition. Blood is needed for oxygen in these tissues, but not a lot. So why are all these vessels here?

As shown above, the reason for this anatomical observation of smaller vessels is merely consistent with fluid biophysical theory (Poiseuille's Law) stating that *resistance of forcing fluid through small tubes will slow the flow down as energy is dissipated*.

WHY HUSBANDRY AFFECTS FOOT HEALTH

To date researchers and hoof professionals do not know what to do with this information, as they believe that the hoof wall is the loading structure. Husbandry can and does have a significant impact. When the foot is not trimmed correctly, the excess vibration causes these tissues to become degenerative. The result is little or no support for the horse

The hoof wall is simply not capable of functioning as the primary loading structure. The changes in the reduction of the vibrational energies passing through the hoof wall occurs at the interface between the wall and soft tissue dermis and its vasculature and then through the coffin bone to the pastern. High vibration damages and causes degenerative changes to the lateral cartilage and foot tissues, which in turn affects the blood flow.[11]

Cutting the frog during trimming so that the sides of it are flat is the worst thing one can do to the frog. It will not touch the ground. Cutting the sides does not permit the frog to develop a functioning vascular cushion within the frog to dissipate energy and support the horse.

Composition of the front part of the frog and density of vessels will vary from horse to horse, depending on what the horse came in contact with. Myxoid tissue in the frog is a unique tissue similar to pre-stem cells. It can adapt to whatever environment the horse lives in. In samples observed, barefoot mountain horses have many more dense vessels than horses on pasture. In navicular horses, ligament and vessels can be seen but they are constricted. (Unpublished)

When the rostral frog is in contact with the ground, and energies are correctly dissipated, myxoid tissue forms fibrous tissue into fibrocartilage tissue. Ligaments change if the frog is on the ground because it becomes more fibrocartilaginous, which is a NORMAL response of fibrous tissue when tissues are subjected to compression; the more fibrocartilaginous, the better.

SUMMARY

The way in which the foot is trimmed, whether with shoes, or without shoes on hard surface, will impact the dissipation of vibration affecting all areas of the foot.

Positive or negative changes to the foot accumulate over a period of months and years. Through histological studies, many pathological changes can be seen in feet long before typical symptoms would be observed. Work at Michigan State University investigated the use of ultrasound on feet before cutting them up for histology. Among other observations, ligaments in the frog were observed to

To understand how a healthy vascular cushion is also important for maintaining health in the front of the foot, see ***LAMINITIS: WHY IS IT GOOD FOR THE COFFIN BONE TO BE POROUS, WHILE IN WOMEN WE CALL IT OSTEOPOROSIS?***

have gaps in them. The ligaments were deteriorating and rupturing. (Unpublished) When there is damage to the fascial sheets, ligaments, and blood vessels, there is less energy dissipation. Energies that are NOT dissipated go to bone and connective tissues to create "arthritic changes". Bones and ligament changes are eventually seen as the "end-stage" changes because vibrational energies are not being dissipated.

Trimming any external tissues of the foot affects more than just those tissues. The unique ability of the horse to adapt positively or negatively to diet, housing, ground surfaces, and especially trimming techniques and appliances, affects how well the foot is able to dissipate energy, support the body, perceive the environment and do the work he is asked to do.

Understanding the internal anatomy of the foot to best help remove or dissipate the impact of energies aids the development of a good foot and significantly affects the long-term health and use of the horse.

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All photos Robert Bowker files.