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Considering the Live Horse: The Impact of Nerves During Laminitis

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As a neurobiologist, understanding the foot as a sensory organ is a primary part of my focus.

Consider these questions:

- How do horses sense their environment?
- Why would they need to? Why would we do that? Do we permit them to do it?
- Do they have receptors in the hoof? Sole? Frog? Other places?
- Can the horse *consciously* seek out comfortable environments for itself?
- Is there any benefit (physiologically or psychologically) for the horse?

Nerves are responsible for how the horse gets sensory information into its body. If you pay attention, you can use these nerves to help the horse in a beneficial way.

Traditional foot science and veterinary medicine has focused on pain sensation, as it is believed to be mediating sensory information of the distal limb lameness. Dissections of cadaver feet have shown only a limited view of equine sensory innervations of the distal limb and do not take into consideration how they affect the live animal. The horse is really interested in the sensations other than pain exclusively, to know how he can begin to be comfortable when standing, to appreciate the ground surface for beneficial as well as harmful objects, and to detect sensory information that may be communicated to them from a distance. The foot and distal limb use these other senses of touch, vibration, and light-pressure receptors in these same regions, which inform the horse about his environment. You don't find this same neural configuration in the other parts of the body.

The skin serves many functions:

- Protection from injury and dehydration;
- Radiation surface and regulator in temperature maintenance;
- Secretion of chemical substances, such as pheromones, that function as attractants or repellents;
- Reception of mechanical, thermal, and possibly chemical stimulation.

We believe the equine foot is similar. The horse's foot has the same sensory receptors we have in our fingertips, suggesting the horse uses the foot in the same way — it searches out the environment to gather information about it.

HOW NERVES HELP THE HORSE

Many attempts have been made in both human and basic research to associate different receptor structures with particular sensations, but no clear relationship exists. Sensations are surprisingly complex with more describable sensations than receptor types to account for them. Obviously the interaction of these various sensory receptors may provide other neural activity that we interpret as other sensations, such as itch, for which there is no specific "itch receptor".

Virtually all nerves within the distal limb are either sensory or sympathetic nerves. Except in the pony, there is no skeletal muscle, so no motor nerves to muscles reside within the equine foot. Within the foot tissues, nerves detect environment via receptors**.**

Mechanical receptors are either free nerve endings or have specialized structures; some have both. In general, free nerve endings are usually associated with the sensations of pain and temperature. The encapsulated endings are associated with light touch and pressure when they lie superficially within the skin. When they lie deep within the tissue, association is with deep pressure and tissue deformation. Hair receptors can be associated with a class of sensations that accompany hair movement.

Several different mechanical receptors throughout the tissues of the horse's foot receive critical information about their environment:

> **Pacinian corpuscle** provides proprioception: "the unconscious perception of movement and spatial orientation arising from stimuli within the body itself"[1]. In humans, you know where your hand is, for example, without even looking. Elephants perceive earthquake vibrations via the Pacinian corpuscle.[23] Heel-first landing activates Pacinian corpuscles in heels, and around the Deep Digital Flexor Tendon (DDFT), a purposeful stimulus needed for reflexes during movement. These are also along the pastern, suggesting that they be very important for detecting foot and distal limb orientations.
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> **Merkel's disks** are in involved with tactile/light pressure. They discharge impulses in response to displacement of the skin, and maintain a discharge of impulses in response to sustained deformation of the skin. Structures appear to be specialized receptor regions in the skin. In the horse they are in the Secondary Epidermal Laminae (SEL), nestled among the basal layer of keratinocytes, and within the epidermal tubules associated with the frog and, presumably, the sole. Merkel's discs can aid in helping with pain relief, similar to when we burn our hands or fingers and we rub the burn site to relieve the burning sensation. Also they can help in opening vascular channels during recovery from a laminitic event when having the horse stand on a softer surface, such as a folded washcloth.[4,5]
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> **Ruffini's endings** inform deep pressure. For example, when you stand, you can feel the pressure in your feet. The horse can sense pressure within the foot depending upon the surface structure.

Our histological work has found these nerves throughout the foot:

> **Pacinian corpuscles** are in the heel bulbs, frog stay, inside the lateral cartilages (LC) at the level of the Navicular bone (NB), and in the DDFT. This shows us that heel-first landing is the desired result to activate these nerves. They are not in the front of the foot.
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> **Free nerve endings** enter tubules of hoof wall as well as along the laminae to provide innervation of Secondary Epidermal Laminae (SEL) for sensations, as well as for controlling tissue perfusion.
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> **The frog dermis contains large nerve bundles** evident in isolation, as well as around vessels: these convey tactile sensations as well as aid in controlling blood flow and perfusion.
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> **Touch receptors** line the epidermal cells along the dermis-epidermal border within the frog. Finger-like projections go up into the higher level of the epidermal cells of the frog tissues to perceive touch.

Merkel cells have been shown via immunoreactivity to be nestled among basal layer of keratinocytes for tactile and light pressure.

Touch receptors are also in the laminae, similar in location underneath the human fingernail.

Merkel cells in the frog perceive the environment. When the frog is removed or atrophied, the horse will have less surface structure to perceive its environment.

There are many touch cells within the epidermal layers, in addition to the epidermal cells.

Ruffini corpuscle receptors (light pressure) are in the fascia over the distal limb and pastern.

LOADING THE FOOT

Tissue nerves detect the environment via receptors. Different nerves detect different stimuli and are affected by load, which can bring light or deep pressure.

With a dirt plug in the sole, the load can be distributed over a wider and more even area on any surface. On a conformable surface, the load is more even.

When standing on pea rock, for example, horses observed are standing on the back part of the foot. The pea rock can be scooped from the front of the foot and we are able to touch the frog. They will stand without moving for 15 minutes. The entire solar surface is bearing weight, not necessarily equally, and each area may become important for detecting and for the sensing environment. (Figure 1)

Figure 1. Two surfaces with different tactile stimuli and perception.

SUBSTANCE P AND LAMINITIS

Substance P is involved in pain. Capsaicin releases substance P from thinly myelinated nerve terminals. Histologically, we have seen that the nerve marking with substance P is contained in that nerve terminal. Most of the substance that is in these nerve fibers, is in the tissues, as opposed to being in the spinal cord. When that nerve is stimulated, Substance P is released into the tissues itself and does good things as well as bad.

Substance P attracts mast cells, which promotes inflammation, causes blood vessels to dilate, and affects the joints. We have shown that with arthritis, the synovial fluid in arthritic joints has higher levels of Substance P compared to the other joints of the same horse. Substance P also attracts white blood cells and other mediators come in to try to get rid of that inflammation.

For example: Stick a pin in yourself. Nerve fibers are activated, and electrical activity goes up your spinal column and to your brain. That is the pain that you feel. The nerves will dump Substance P into your tissue. If this is just a one-time pin prick that is good — the area will get red. Blood vessels will be dilating. Fluid will leak out as blood vessels get bigger and bigger. The inflammatory response begins; white blood cells come in. Then in two days you will have an abscess. This is a good thing. You will heal.

However, in conditions like laminitis where the condition becomes acute or chronic, the substance P response just continues; it does not stop. The chronic release of substance P from the sensory nerves will turn tissues within the foot turn to hamburger. In laminitis the hoof wall changes, but the inside of the foot is also changed from the chronic and acute action of these chemicals.

Pharmacological research indicates that Phenylbutazone (Bute) works in the brain (i.e., midbrain) to block pain input.[6] When a painful stimulus in the tissues is encountered, and the nerves release Substance P, the brain does not perceive it. The Substance P effects, however, are very widespread in promoting the inflammatory response. Bute is a centrally acting drug and does not work on the periphery to alleviate pain and inflammation that emanates from the tissues. Bute *does* decrease the prostaglandin production in the tissues, which can decrease certain aspects of the inflammatory processes.

NERVES AND BLOOD FLOW

Unlike humans, the veins in the horse pulsate to return blood back to the body/heart. This function of the veins serves as gatekeepers or regulators of blood flow. In the horse, sensory activation from environmental influences will affect blood flow through the foot.

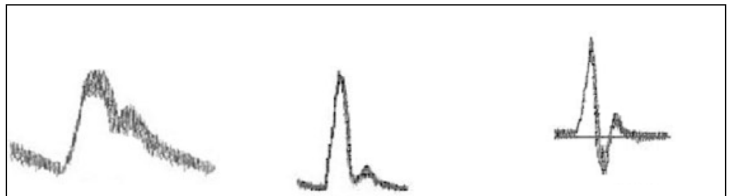

Figure 2. Doppler waveforms showing the variation in pulsatility or how rapid the pulse wave is achieved. Low pulsatility means that the wave pulse reaches its peak slightly slower (greater time period) than other waveforms, with a high pulsatility wave being very rapid. In the high plurality wave, the peak is achieved quickly, as most of the blood flow detected by the probe has similar features. This rapid rise to peak pulse would be often observed in a horse with laminitis and often described as a bounding pulse. Robert M. Bowker files.

The foot is really a neurosensory organ. Central nerves are very important. When one foot is stimulated, the sensory nerves will effect a change in the opposite foot. To show the significance of this, horses in our research stood bilaterally on various surfaces. The blood flow was measured via Doppler ultrasound at the level of the fetlock, measuring the waveform characteristics: acceleration, the wave form, amplitude, and other measurements.[7,8] (Figure 2)

When standing with the foot doubly loaded on concrete, tissue perfusion of the foot dramatically decreased, with blood flow coming almost to a halt for a split second during the diastolic phase in some horses.

In the live horse, the sensory nerves can be activated via tactile/light pressure receptors (Merkel cells) and can affect vascular perfusion through the foot. Doppler ultrasound work also demonstrated this effect with the simple use of a washcloth under the foot on a cement floor. Standing solely on cement, the surface area of loading is small and so the tissue pressure increases — similar to high heels in women. If the pressure in tissues rises to equal or surpass that within the vessels, the forward flow of blood will stop or go backward, similar to that with a sphygmomanometer during a blood pressure examination. Now if the same horse stands on a wash cloth between the foot and cement block and the opposite foot is elevated, the loaded foot becomes doubly loaded again. However, as a result of the touch receptors being activated the blood flow through the foot returns velocity to normal. This is what the Merkel cells do when activated with tactile stimuli.

The blood flow through that foot slows down because the tactile stimulus of the cotton washcloth facilitates more smaller blood vessels to open. By adding just the light tactile sensation of the cloth, the blood goes through many more vascular channels, and actually slows down as it is exiting the foot. It is like watering a garden by using sprinklers with many smaller-diameter drip hoses: the water slows down when exiting.[9] This slowing down of blood flow through the foot is increasing the perfusion of the tissues.

Additionally, blood flow output was recorded in the *opposite* foot that *did not* have a washcloth beneath it: blood flow slowed in that foot as well, although not as much. This information is carried to the opposite side of the body via sensory nerves.

LAMINITIS AND FOUNDER — WHAT TO DO FOR PAIN

You can use nerves to your advantage. In laminitis we need to reduce pain in periphery tissues as soon as possible.

In a horse with painful, acute or chronic laminitis and founder, nerves are stimulated from the new displacement of bone within the foot; they are constantly shifting their weight from foot to foot. To alleviate the pain, the horse must be made as comfortable as possible, as quickly as possible, via corrective trim and conformable surfaces. Initially, quite often we provide a towel or other cushion-like like surface for them to stand on. This towel increases the surface area a little but perhaps more importantly it alters the texture that the foot perceives. This in turn improves perfusion within the foot. Reducing the hoof wall as loading structure via trim and the use of softer pads are critical to make the horse more comfortable and to improve perfusion within the foot.

Take the quality of the pulse before trimming. Normal foot blood flow will vary 40-60 cm per second. A laminitic horse will vary, but it is generally by 80-120-150 cm per second — a bounding pulse. The recording shows not only the number for heart rate but also assesses the quality of the pulse. It is an instantaneous physiological indicator of what is functioning in the foot in terms of perfusion and vascular obstruction. A bounding pulse means the blood is going past your finger very fast, with a lot of resistance downstream. We've seen some horses with over 200 cm per second. Blood is going in through the digital artery and coming right back out the digital vein, doing nothing to perfuse the foot.

The pulse should be less bounding and smoother after the trim. If your trim is helping, the resistance inside the foot becomes less as the smaller vessels open. The rate of the heart should stay the same. If during trimming, the pulse gets more spiked you are not helping the horse. The vessels are becoming more restricted.

Even in a healthy horse you can find a pulse difference before and after trimming.

By using softer, more conformable surfaces, more tactile information will go up the foot. Nerves will trigger the opening up of the vascular channels for greater perfusion through the foot.

Like your garden and water hose hooked up to the sprinkler/trickle system. You want to direct the water in a slower fashion; if you use just the garden hose, it will blow away the soil as the force will be too great. Using a sprinkler or trickle system will allow the water to get to the plants in a slower but more complete and beneficial fashion. Same with the foot. Open the smaller vessels in the foot and the blood flow gets slower and slower, thereby reducing pain.

For acutely laminitic horses, we often use ice. In hind-gut acidosis, we are trying to prevent the toxins leaking from the hind gut from reaching the foot and leaking out in to the tissue. The toxins will slowly be cleaned up in the hind gut so that you by-pass the toxic episode. If the horse is laminitic for several days, it really does not do any good to put the horse's foot in ice. Whatever damage that has been done, is done.

In hormonal laminitis, inflammation takes place in the first few hours. Ice will not help pain relief past that point. Regular, corrective trims and conformable surfaces are the key to pain relief for these horses.

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