Digital Venography in Horses and Its Clinical Application in Europe

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Venography is a useful diagnostic tool that allows radiographic visualization of the veins in the equine foot after an injection of radiopaque contrast liquid into the digital palmar or plantar vein (Fig. 1).

The technique is repeatable and is useful as a diagnostic procedure to clinically evaluate the severity of the vascular changes in laminitis, or other foot pathologies, in the standing horse. With a tourniquet applied, the circulation in the foot is closed and sometimes arteries are also visible because of retrograde filling of the arterial circulation. Venography provides the equine veterinarian with important information regarding the clinical evaluation of the vascular changes of the laminitic foot (Fig. 2). The procedure can be easily and safely performed in the standing, sedated horse with an abaxial sesamoidean nerve block and tourniquet applied; only routine radiographic equipment is required and complications are minimal. The venographic examination continues to evolve since its introduction 18 years ago.

HISTORY OF DIGITAL VENOGRAPHY

Using cadaver limbs, with a tourniquet applied proximal to the injection site, Pollitt1 in 1992 showed retrograde filling of digital veins when radiopaque contrast fluid was injected into the lateral digital vein. Later, in 1992, Redden and Pollitt collaborated and developed a reliable technique for the standing horse because a great need existed then to better understand the effect of laminitis on the digital circulation. Thereafter, Redden3,4 standardized the digital venographic technique and used it extensively as a diagnostic tool in clinical practice. Rucker5,6 has described normal
aspects and artifacts of the digital venogram, and D’Arpe and Bernardini and others have described modifications to the venography technique exploring the biomechanical influence of foot loading on the vascular network during quasistatic movement.\textsuperscript{7,8} The authors have studied and used the technique to assess the chronology of laminitis development to provide basic guidelines for the interpretation of sequential venograms. Furthermore, the authors have used venography to investigate the physiology and biomechanics of the “hydrovolumetric foot-heart pump.”

**COMPARING DIGITAL BLOOD FLOW DIAGNOSTIC TECHNIQUES**

Various in vivo and in vitro methods have been used to gauge blood flow in the feet of laminitic horses. They include angiography by way of the digital artery, thermography,
scintigraphy, infrared spectroscopy, magnetic resonance imaging, ultrasound, and laser Doppler fluxometry. Some of these techniques are non-invasive. Angiography, however, calls for general anesthesia and lateral recumbency and can cause arterial spasms, which may affect the results. These techniques are not readily available in clinical practice and, in the authors’ experience, are not predictive of tissue damage because none allows visualization of venocompression because of pathology (permanent) or the dynamic forces of foot loading (temporary). Venography helps the veterinarian in the clinical evaluation of foot perfusion in the standing, conscious horse. Venography has a predictive potential thanks to the visualization of venocompression; this enables the clinician to anticipate tissue necrosis instead of detecting it after it occurs.

PODIATRY RADIOGRAPHIC TECHNIQUE AND HOW IT DIFFERS FROM TRADITIONAL ORTHOPEDIC PROCEDURES

The equine foot is the anatomic region most frequently examined using radiographs because many horse gait abnormalities result from foot problems. Many scientific studies on radiologic foot measurements exist, but they were not performed using a positioning technique standardized for foot venography. A few techniques have been standardized for postmortem studies. When the x-ray beam is focused on the distal interphalangeal joint (DIP), the image obtained shows superimposition of the condyles of the middle phalanx and lateromedial imbalance. The palmar angle (PA) of the distal phalanx is also distorted (PA is the angle between the palmar processes of the distal phalanx and the ground surface). The authors conducted a study evaluating the “magnification effect” related to the focus-film distance and the “distortion effect” related to the height of the block used to position the foot. It was concluded that an 80-cm focus-film distance was a good compromise between quality images and radiation safety.

When the foot was radiographed without the foot placed on a wooden block, the x-ray focus was on the proximal interphalangeal joint, with a 50-mm woodblock the x-ray focus was on the DIP, and with a 90-mm woodblock the x-ray focus was on the middle of the solar aspect of the distal phalanx. Distortion caused by the height effect did not influence the coronary band–extensor process distance (CE). There was a remarkable variation, however, in the PA and lateromedial imbalance. Lastly, sole depth (SD) measurements were compromised if a shoe or the wooden block were superimposed on the image. An evaluation of distortion caused by the height of the foot positioning block is shown in Fig. 3.

Centering the beam is particularly important for venography because one of the main goals of digital venography is to properly visualize, without distortion or magnification, the papillae or fimbriae of the solear dermis (fimbriae = fringe in Latin). Solear papillae can be obscured by superimposition of the palmar processes or a shoe. The length, direction, and compression of the solear papillae are clinically correlated to foot pathology and to biomechanical forces acting on the foot (Fig. 4).

DIGITAL VENOGRAPHY PROCEDURE IN THE STANDING HORSE

The anatomic structures detected with venography are soft tissues that are undetectable with plain radiographs. The authors perform the technique according to Redden and Rucker with some modifications, such as a screw-on injection site on the butterfly needle tubing to avoid blood contamination of equipment and the operator’s hands. Additional radiographs are acquired at 90 and 160 seconds.
Fig. 3. The distortion effect caused by X-ray beam angle can cause errors when measuring the PA and lateral medial imbalance (LMU).\textsuperscript{18} For every barium dot on the digit there is an arrow that shows the corresponding radiograph. A postmortem study determined which X-ray examination technique gave the most realistic measurements of the SD, CE, PA, and LMU. (Data from D’Arpe L, Coppola LM, Bernardini D. Radiographic imaging of the equine foot. International Laminitis Symposium Proceedings, Berlin; 2008.)

Fig. 4. Comparing radiographic and anatomic measurements. Red arrows show the measurements on the radiograph compared with the corresponding anatomic measurement. The study was performed on shod and barefoot horses taking several images at different heights of the X-ray beam; the SD, PA, lateral medial imbalance (LMU), and CE were calculated for each image. We confirmed that measurements of the SD, PA, CE, and LMU using a standardized, podiatry X-ray technique and derived when the X-ray beam was aligned with the palmar surface of the distal phalanx corresponded closely to postmortem measurements. Measurements were corrected for magnification error using a magnification correction coefficient with an 80-cm film/focus distance.
The horse is sedated with detomidine and the foot desensitized with a subcutaneous injection of 2% lidocaine, abaxially, to the medial and lateral palmar nerves at the apex of the proximal sesamoid bones (abaxial sesamoidean nerve block). The shoe is removed and the foot is cleaned thoroughly. An adhesive bandage is placed around the fetlock to secure the tourniquet when it is applied. The foot is placed on the foot.

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**Fig. 5.** Normal anatomic structures detected by venography. (A) Coronary venous plexus. (B) Dorsal sublamellar veins. (C) Circumflex vessels. (D) Terminal arch. (E) Bulbar vessels.

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**Fig. 6.** Venography materials. (A) A 21-gauge butterfly needle with 30-cm tubing. (B) Sterile screw-on injection cap. (C) Two to three syringes containing 10–12 mL radiopaque intravascular contrast medium, sodium diatrizoate. (D) Tourniquet (or Esmarch bandage). (E) Elastikon (Ethicon USA, Sommerville, NJ, USA) 10 cm (or other adhesive bandage). (F) Detomidine (or other sedative). (G) Barium sulfate paste.
block and the butterfly needle is inserted, mid-pastern, into the lateral or medial palmar or plantar digital vein. As soon as the vein is catheterized and venous blood flows freely, the cap is screwed in place to close the tube. After the 20 to 25 mL of contrast fluid is injected, the butterfly needle tube is secured to the bandage that holds the tourniquet in place. Four radiographs are acquired (two lateromedial views and two dorsopalmar 0-degree views) in 40 to 50 seconds, so as to obtain optimal images before the contrast medium diffuses from the veins. We then take one more lateromedial projection at 90 seconds to visualize and evaluate the rate of perivascular diffusion and, lastly, at 120 seconds a 65-degree dorsopalmar oblique projection to detect the presence or absence of inflammatory edema or seroma that may be present in acute or chronic recurrent laminitis.

The authors have observed that “pumping” (Fig. 7) between the second and third radiographs at 10 and 30 seconds is a useful variation on the original technique described by Redden.4 It is not advised, however, for clinical venography of severe acute cases because it may exacerbate pathology.

The authors usually perform pumping on normal and low-risk cases. By completely unloading the foot and studying before and after pumping venograms (Fig. 8), the effect of prolonged, static loading on the venogram can be determined.19

Routinely, the authors unlock the carpus during injection of the contrast agent to slightly unload the foot and relieve the tension of the deep digital flexor tendon (DDFT). This achieves filling of the dorsal laminae.4 The foot is unloaded while injecting the second syringe of contrast medium to ensure lamellar perfusion. Lamellar perfusion is compromised when the foot is weight-bearing (loaded).3,4 In venograms of a normal foot, vascular filling in the dorsal laminae can be substantially reduced4 by venocompression if the foot is weight-bearing and immobile for a prolonged period

![Fig. 7. Pumping the foot to detect venocompression. The horse's leg is held while the operator's shoulder is in contact with the dorsal forearm of the horse; one hand pulls the deep digital flexor tendon muscle to pick up the foot while the other hand replaces the foot to its original place.](image-url)
of time (see Fig. 8A). Also, if normal horses stand still on the radiograph blocks for more than 10 minutes, and the procedure is then started, a lack of contrast in the dorsal lamellar vessels is observed. This is the normal effect of static venocompression caused by prolonged weight-bearing.

ARTIFACTS

In normal venograms, retrograde venous infusion of radiopaque contrast material should fill the venous vessels and sometimes the arteries. In abnormal venograms, retrograde venous infusion of radiopaque contrast material fails to completely fill the vessels of the foot. This can be temporary (caused by prolonged weight-bearing) or permanent (caused by advanced lamellar pathology and necrosis or by technique failure).[10–20]

Perivascular infiltration of contrast medium is the most frequent artifact found in the venographic technique.[5] If perivascular leakage has occurred, a large pool of contrast medium is evident on both the lateromedial and dorsopalmar views, at the needle insertion site, in the palmar or plantar digital vein (Fig. 9). The quantity of leaked contrast must be taken into consideration because it may result in inadequate venous filling of the foot.[7,21]

An inadequate volume of contrast medium results from perivascular leakage; syringes coming loose from catheters; loosened catheter clamps (if used); or from incorrect calculations of the volume needed for the venogram. Contrast volume varies with foot size: 20 to 25 ml is the range for the foot of a small horse (300–450 kg body weight, 9–12 cm diameter at the widest part of the foot) and 25 to 30 mL is adequate

Fig. 8. The before (A) and after (B) effects of “pumping.” There is more complete filling of coronary and sublamellar vessels after pumping.
for the foot of a large horse (450–700 kg body weight, 12–15 cm diameter at the widest part of the foot). Inadequate volume can be confused with poor perfusion. A characteristic narrowing of the blood vessels and lack of perfusion in the heels indicate that volume is inadequate (Fig. 10).5,21

Tourniquet failure can also result in inadequate filling. Radiographs reveal contrast medium proximal to the tourniquet (Fig. 11). Elastic adhesive bandage (Elastikon; Ethicon USA, Somerville, NJ, USA) placed beneath the tourniquet to prevent it from slipping is recommended, but using too much Elastikon to pad the vessels can impair tourniquet function.5,7,21

In the authors’ experience, use of the tourniquet at mid-cannon, as described for the retrograde venous antibiotic perfusion technique, makes it more difficult to achieve an adequate volume of contrast medium and is more likely to cause tourniquet failure.

VENOGRAPHIC STUDIES OF THE QUASISTATIC BIOMECHANICS OF THE FOOT

Shearing and compressive forces within the hoof capsule caused by downward displacement of the laminitic distal phalanx contribute to mechanical circulatory collapse, hoof lamellar and solear pathology, and impact directly on varying degrees of inflammation and lysis of the distal phalanx.3,4 The authors have used venography

Fig. 9. Perivascular leakage of contrast material can occur if the vein is punctured during catheterization. It also occurs if the horse moves during the process, or the catheter comes out of the vein during foot manipulation, or if the digital palmar vein pressure is so high that the liquid escapes from the vein.

Fig. 10. An inadequate volume of contrast medium has been injected. There is lack of perfusion in heel veins and blood vessels appear narrow (compare with Fig. 1).
to visualize and evaluate how in vivo venocclusion is influenced by weight-bearing forces. In the authors’ opinion this is a clinically important factor in the laminitis process. The weight-bearing force is transmitted through the skeletal axis to the ground at one application point: the static center of pressure (SCP) as described by Leveillard.\textsuperscript{22} The SCP can be easily detected and its position varies depending on whether the horse is in the quadripedal or tripedal stance. Differences in weight-bearing load and balance regulation influence tension in the DDFT musculotendinous unit and can modify the venographic appearance of the digital vascular bed (Fig. 12).\textsuperscript{23}

Fig. 11. Failure of the tourniquet. There is contrast proximal to the tourniquet (arrow). (Courtesy of Richard Corde, Boissy St Leger, France.)

Fig. 12. Venograms of a club foot loaded (A), unloaded (B), and after deep digital flexor tendon tenotomy (C) at mid cannon. A change in tension in the deep digital flexor tendon musculotendinous unit has modified the venographic appearance of the digital vascular bed; there is increased venous filling after tenotomy. (Courtesy of Ric Redden, Versailles, KY, USA.)
The PA of the foot, and consequently the flexion-extension of the phalangeal joints, can modify the appearance of the venogram in the same horse, in the same time frame, even under constant overloading (tripodal stance).\textsuperscript{24,25} In an in vivo study we used a dynamic PA iron and wood block called the D’Arpe-Moreau block (built for research purposes only). The aim was to visualize the vascular bed while the PA of the weight-bearing foot varied (Fig. 13). Using our standardized technique contrast medium was injected with the foot at 0 degrees. After injecting the contrast liquid, the contralateral foot was picked up to induce a tripedal stance. The foot was then progressively moved from $-15$ degrees to $+15$ degrees and vice versa; the head of

![Fig. 13](image)

Fig. 13. A foot was prepared for venography and digital venograms were made with the D’Arpe-Moreau block at $+15$ degrees (A), 0 degrees (B), and $-15$ degrees (C). The contralateral limb was kept raised while the radiographs were acquired. The coronary plexus is circled in each venogram. There was less dorsal, venous filling when the toe was raised by 15 degrees (A).
the horse was kept in the sagittal axis to keep the weight on the foot constant. Seven radiographic images were acquired while moving the dynamic woodblock angle by 5 degrees every 30 seconds and not moving the x-ray machine from the ground.

The study showed that manipulating the PA of a loaded foot caused an alternating emptying and filling of vascular regions within the foot, suggesting that the foot, with a tourniquet applied, is an anatomically closed system. The authors concluded that the equine foot is a hydraulic pump able to develop alternating emptying and filling of blood between the hoof capsule and the distal phalanx.40

THE SAFETY VALVE OF THE FOOT-HEART PUMP AND THE FIVE-HEARTS THEORY

The discoveries made by the authors, using the D’Arpe-Moreau block, contradict the traditional foot pump theory. In addition, observation of the pumping action during flexion-extension of the DIP suggested a safety valve function for the coronary band. There is an interface between an abaxial flap consisting of the coronary band and the axial flap consisting of the ungual cartilages, the collateral ligaments of the DIP, and the dorsal digital extensor tendon. The latter seem to be involved in compression of the coronary venous plexus during extension and decompression during flexion, closing and opening the blood flow to the foot vascular bed in the standing quasistatic horse.20,26

Pollitt1 showed in an ex vivo experiment that when the digit is loaded with a 1000-kg pressure (as on the foot of a galloping horse) and contrast medium is infused by way of the common digital artery, no arterial contrast was visible below the coronary band. The contrary occurred when the foot was not loaded; the infusion of contrast medium then filled the whole vascular network (Fig. 14).

Previous studies described the foot-heart pump as a hydraulic pump activated by flexion and extension of the DIP that empties and fills with blood inside the semiclosed system of the foot vascular bed. In a dynamic or quasistatic state the body weight movement over the SC induces flexion-extension of the phalanges. Tension and release in the DDFT modulates phalangeal flexion and extension and moves the SCP, biomechanically opening and closing the vascular arterial and venous safety valves. The foot pumping action, during quasistatic movement in standing horses, resembles the shifting weight behavior or paddling of laminitic horses described by Obel27 as grade 1 laminitis in 1948. The rolling foot action has a massaging effect that moves the SCP backward and forward, even under constant overload, and without leaving the ground.

The conclusion is that the equine foot is a hydraulic pump with the coronary band acting as an anatomic safety valve, regulated by weight-bearing. In the standing horse, limb loading at low weight range less than 180 kg apparently has no appreciable effect on biomechanical venocompression. Limb loading at a medium weight range (220–330 kg) shows that the foot is able to alternately empty and fill, even under constant load, by flexion-extension of the DIJ. In the moving horse, at higher load range, the anatomic safety valve is completely closed to blood flux to protect the foot from excessive arterial pressure during full load.1,26,28 Further investigations are required to clarify these observations.

Bouley29 in 1851 (quoted by Bossi30 in 1928) called the equine foot an “enclosed heart,” a second “pulling and pushing vascular pump” that was biomechanically activated by the elastic properties of the foot during locomotion. Bouley underlined the important use of this pump for the horse because of the position of the foot at the most distal position of the limb where blood needs more pushing to flow in the veins and return to the heart. The authors have formulated a “five-hearts theory”: “a horse
standing absolutely still has only 1 heart, while a moving horse has 5 hearts—one more for each foot. Nevertheless, a horse in quasi-static movement also has 5 hearts."³⁰

These in vivo studies support the concept that self-adjusting PA massaging shoes³¹ (Four Point Rail Shoe, Nanric USA, Versailles, KY, USA) or boots that offer a dynamic in static effect (5 Iced Heart Boots, Stilgomma Italy, Castelli Calepio, Italy) improve the foot pumping action, even during full and constant weight-bearing (Fig. 15A, B).

**CLINICAL RELEVANCE OF VENOGRAPHY IN LAMINITIS AND OTHER SOFT TISSUE DIGITAL PATHOLOGIES**

The etiology of laminitis continues to be controversial and not entirely understood. Venography offers a mean of assessing the circulatory system of the digit at various stages of laminitis development. This information helps the veterinarian and farrier develop protocols designed to mechanically and therapeutically address forces that directly restrict perfusion of the digit. It can also be used as a diagnostic tool for soft tissue lesions. Comparative, sequential venograms can become a valuable prognostic indicator along with careful clinical observations.³,⁴

Venography has shown its repeatable usefulness as a diagnostic procedure to clinically evaluate the severity of the vascular damage in laminitis or other foot pathologies.
in the standing horse. The key value of venography is to check, monitor, and detect whether the examined foot is responding to therapy or is making no response and requires a different or more aggressive therapy. Sometimes pathology is irreversible with all available therapy.

In the authors’ opinion the value of venography is independent of the presence or absence of pain because there is no need to walk a horse to clinically evaluate laminitis severity. This avoids the risk of forced walking inducing further mechanical trauma to the hoof lamellar dermoepidermal bond.

Venography predicts distal phalangeal displacement and the associated vascular changes. This is in contrast to conventional, plain radiography, which shows distal phalanx displacement and rotation after they have already occurred. Rotation and founder distance (CE) lack predictive value because they occur after the vascular damage. Detection of the continuous and rapid changes in the vascular architecture in laminitis requires venography. Venography enables clinicians to monitor vascular lesion development and to check the success of their therapeutic protocol.

Venography is relatively easy to perform, but image interpretation and data analyses are somewhat difficult. Focused experience brings timely and accurate diagnostic validity to the venographic examination. Venograms on 10 horses designated for euthanasia for non–foot related reasons showed no lesions that could be attributed to venography when compared with untreated controls. Venography seems to be a clinically safe technique.

**LAMINITIS PHASES: CHRONOLOGY AND SEVERITY SCORE**

Understanding the time line of disease development is very important in the clinical evaluation of laminitis. It enables improved treatment and monitoring. Clinically, the authors observe two main events that predict catastrophic laminitis: the first at around 72 hours (inflammatory laminitis) and the second at 3 to 6 weeks (load-induced laminitis) from onset of the first pain event. The authors have pinpointed these two events as indicative of the passage from the developmental-acute to the chronic phase of laminitis.

Developmental laminitis mechanisms are, according to Kyaw-Tanner and Pollitt, related to increased lamellar metalloproteinase activity and perturbed glucose metabolism that produce histologic and ultrastructural lesions that already exist before the onset of the visible pain. Insulin resistance and an attendant hyperinsulinemia are
also associated with inflammatory laminitis development because there is an essential need for glucose by hoof lamellar hemidesmosomes. In supporting limb (contralateral or load-induced) laminitis (SLL) the failure of glucose to enter hoof lamellae compromises hemidesmosome metabolism and contributes to lamellar dermoepidermal separation and downward displacement of the distal phalanx. The time from onset of symptoms (pain, digital pulse, heat in the coronets) to the development of the initial catastrophic event is around 72 hours.

The mechanism responsible for load-induced laminitis is, from the authors’ observations, constant overload and immobility of the foot. This causes prolonged ischemia because of the inefficient action of the foot hydraulic pump and biomechanical veno-compression. Pain is unpredictable and may not appear until the constant weight-bearing and the associated lamellar hypoxia has resulted in laminitis. The load-induced laminitis event (SLL), when extant and clinically evident with intractable pain, is rarely reversible with therapy and euthanasia is often the necessary outcome.

Laminitis can be manifest in varying degrees of severity and venography can help differentiate what is normal or mild from what is potentially catastrophic. The authors recognize developmental; acute (72 hours); subacute intermediate (until 3–6 weeks); and chronic laminitis (after 60 days). The latter can eventually lead to (1) restitutio ad integrum (return to normality); (2) life-long chronic asymptomatic laminitis with a clinically compensated lamellar pathology; or (3) symptomatic laminitis with clinically uncompensated lamellar pathology. It is the authors’ observation that clinical compensation is often related to sole depth (SD), a parameter easily measured with a podiatry radiograph.

The Normal Foot

The range of normality is very broad because the vascular network can be influenced by different factors: weight of the horse, normal anatomic variations, and other organic or apparatus-induced pathologic variations. Because the starting point is different for each foot, each case must be approached with an eye to the structural characteristics of that particular foot. Structural integrity of the foot is important and SLL or load laminitis is more likely to develop in a foot with a thin sole, low heel, negative PA, hoof wall defects, or other structural abnormalities absent in a healthy foot. SLL is also manifest earlier in a weak foot than in a stronger one and is more difficult to manage successfully. In most horses with healthy feet and strong heels, the PA is in the range of 3 to 5 degrees. Papillae of the solar corium are often not evident on a thin-soled horse. Although such horses may not be lame, inadequate SD and an implied lack of blood supply are far from ideal.

In our retrospective study of 54 cases with loss of performance, horses with a SD of less than 15 mm were more inclined to palmar foot pain and pathology. Front feet radiographs were made of all horses and 14 horses underwent venography. The radiographs showed no vertical dislocation or rotation of the distal phalanx but SD was less than 15 mm. Venography showed compression of the solar papillae or fimbriae (Fig. 16). Horses with a SD of less than 15 mm were more inclined to inflammation of the solar corium. SD is, at present, the best measurement for quickly and easily summarizing a guideline reference for foot health.

Developmental laminitis

This phase begins with exposure to one of the long list of primary causes or predisposing factors and ends when clinical signs of pain appear. During the laminitis developmental phase, there may be few clinical signs and laminitis is subclinical; occasionally there are increased digital pulses and warm coronets. Horses often show no
symptoms, but venography reveals mild alterations. The authors observed that the time span of this phase is variable (hours, days, weeks, or indefinitely) depending on previous foot health and biomechanical foot management.

**Acute Inflammatory Laminitis**

This phase begins with the onset of typical clinical signs of pain and ends at 72 hours with the first venographic evidence of an irreversible venocompression of the papillae of the dorsal third of the solear dermis. The authors interpret this as evidence of pressure necrosis onset and correlate it to the development of primary dermal lamellar hemorrhage that has weakened the suspensory apparatus of the distal phalanx. Dermoepidermal separation and vertical dislocation of the distal phalanx are events that follow the appearance of the irreversible, solear venocompression. During this phase there is a marked digital pulse, warm coronets, the characteristic laminitic stance, and lameness. In this phase it is possible to clinically score the damage using venography. The risk of causing further mechanical damage by walking or trotting the horse is thus avoided.

**Low-severity damage**

Venography shows the dorsal lamellar vessels are present. There is little compression of the circumflex vessels and papillae are distorted dorsally. There is normal perfusion of the terminal arch and the coronary plexus appears close to normal.

**Medium-severity damage**

The dorsal lamellar vessels are absent. Dorsal circumflex vessels are compressed because of downward dislocation of the distal phalanx. There is normal perfusion of the terminal arch. The coronary plexus is compressed at the extensor process, but intact in the pulvinis coronae. The damage is visible in the first few hours with a venogram and before plain radiographs show an increase in CE distance, an increase in distance between outer hoof wall and dorsal distal phalanx, and decreased SD.

**High-severity damage**

Dorsal lamellar vessels are absent and there is vertical dislocation of the distal phalanx apex that prolapses below the dorsal circumflex vessels. The coronary plexus is void
of contrast medium at the extensor process. In cases of particular severity, the coronary band seems to act as a tourniquet. Plain radiographs show a further increase in CE distance, an increase in the thickness of dorsal horn-lamellar zone, and a progressive decrease in SD.

**Supporting Limb (Load) Laminitis**

This condition develops during a period of abnormal, prolonged weight-bearing on a single limb and becomes clinically evident when pain is present. Clinical signs are often less evident than in the development of other types of laminitis and this fact too often gives the clinician a false sense of security concerning the supporting foot: “if the horse is not showing signs of discomfort, then there is no problem.”

According to Redden, lamellar degeneration in the supporting foot likely begins within a few hours of constant loading, although the clinical manifestations of SLL appear around 4 to 6 weeks postinjury.

Clinically, these horses often show mild or absent pain during the development phase despite the presence of venographic filling deficits. Sometimes, around 3 to 6 weeks, without any clinical indications, an unpredictable, catastrophic painful event occurs revealing lesions that are already well developed and, unfortunately, often irreversible.

Horses may pass through the developmental and acute phases and, either because the inciting condition was mild or therapy was successful, their symptoms become subclinical. They can be considered restitutio ad integrum (restored to normality).

The authors have observed restitutio ad integrum after applying prolonged cryotherapy to horses with early, severe acute laminitis. The feet were monitored by venography for 60 days and with plain radiographs every month thereafter. With prolonged cryotherapy and quasistatic massaging the damage and risk severity scores remained low during all the laminitis phases described previously. Furthermore, there was less need for surgically aggressive interventions, such as DDFT tenotomy, wall ablation, and transcortical casting as is usual in the clinical handling of these cases.

When the foot returns to apparent normality the potential remains for it again to develop clinical signs of laminitis. As mentioned previously, a thin-soled foot with a negative PA is more prone to redeveloping laminitis than it was the first time.

**Chronic Recurring, Uncompensated Laminitis**

This phase starts 6 weeks after the acute phase and ends when the horse is pain-free. The distal phalanx damage is irreversible but bone remodeling speed can be slowed by biomechanical manipulation and increased sole protection. Horses may continue to show intermittent, life-long pain that correlates to SD and damage to circumflex vessels because of vertical dislocation of the distal phalanx. Rotation is, in the authors’ experience, a helpful but not significant parameter for prognosis. Biomechanical therapy and prolonged cryotherapy may prevent the rotation process and the associated pathology but in some cases the speed at which dorsal lamellar vessel damage occurs and the degree of lamellar dermoepidermal pathology makes rotation irreversible.

**Low-severity damage**

In this phase dorsal, sublamellar vessels are present but only in the distal third. There is mild compression of the circumflex vessels and terminal papillae are distorted dorsally. There is normal perfusion of the terminal arch and the dorsal coronary plexus
is close to normal. Venography confirms distal phalanx rotation without vertical dislocation. A seroma is sometimes present.

**Medium-severity damage**
Dorsal sublamellar vessels are present but reduced in density and present only in the distal third. Circumflex vessels are compressed with a typical long stretched appearance proximal to the apex of the distal phalanx. There is normal perfusion of the terminal arch but the coronary plexus is compressed and void of contrast.

**High-severity damage**
Dorsal sublamellar vessels are absent but sometimes visible after pumping. Circumflex vessels are absent or compressed and dislocated above the apex of the distal phalanx. The coronary plexus is compressed and dislocated distally inside the hoof capsule. The terminal arch is poorly perfused and the semilunar canal of the distal phalanx is enlarged because of remodeling and is abnormally close to the distal margin of the distal phalanx. The vascular damage detected with venography predicts a major problem.

**Very high-severity damage**
Bone remodeling and extensive osteolysis has removed most of the semilunar canal and the terminal arch is no longer protected within it.

**CONSIDERATIONS AND CONCLUSIONS**

The technique of venography is relatively easy to perform; however, image interpretation and data analysis require a large number of cases and daily practice before the technique has precise diagnostic value. Because of the many variables found among breeds, conformation, environmental influences, and foot health and management, the authors encourage colleagues to become competent with the procedure and to develop a specialized working knowledge of normal feet before attempting to use venography in clinical practice.

When a tourniquet is in place, the vascular bed of the foot is an anatomically closed system; the vessels are enclosed between the hoof capsule and the distal phalanx. The authors interpret the studies of Pollitt\(^1\) to suggest that the coronary band and ungual cartilages act as a safety valve for the foot by closing arterial blood and opening venous flow when the foot is loaded. With the horse in the tripod stance and one foot overloaded it is still possible to create variations in pressure and volume by manipulating the PA and changing the distribution of the weight-bearing load and the location of the SCP. These results tend to confirm Redden’s observation\(^23\) that raising the heels to produce a positive PA preserves vascular perfusion of the dorsal laminae even during full weight-bearing. It follows that contralateral limb laminitis may be preventable in at-risk patients by mechanically supporting the weight-bearing foot in a way that preserves dorsal lamellar perfusion during full loading.

The five-hearts theory opposes the traditional concept that the foot pump depends on digital cushion compression and the relative enlargement of the hoof capsule during the load phase. Instead, the authors propose that the action of the foot-heart pump is attributable to flexion and extension of the DIP emptying and filling the vascular bed enclosed between the hoof capsule and the distal phalanx. Furthermore, quasistatic movement opens and closes blood flow to the foot by its action on the
coronary band and the ungular cartilages. Compression of the coronary plexus (venous blood flow out) occurs during extension (negative PA) and relaxation (arterial blood flow in) occurs during flexion (positive PA).

Besides its documented usefulness in laminitis diagnosis and prognosis, venography may also have some therapeutic action, because the clinical condition of severely laminitic horses undergoing venography tends to improve. This suggestion requires confirmation by scientific study. Nevertheless, the authors have seen clinical improvement in feet that have undergone venography. Perhaps the hyperosmotic contrast medium, by reducing interstitial edema, alleviates pain.

The authors suggest that venography is superior to plain radiography because the destructive changes in vascular architecture, associated with laminitis, can be detected early and can be continuously monitored. Vascular compromise, as evidenced by venography, appears on the laminitis time line days or weeks before vertical dislocation and rotation of the distal phalanx. Venography enables clinicians to treat laminitis proactively and prevent the pathologic consequences of prolonged vasocompression and ischemia. A clinician performing venograms on horse feet detects and treats the laminitis pathology earlier and more effectively than one relying on plain radiography.

The key to minimizing the destructive potential of laminitis is to support the weight-bearing foot in a way that maintains lamellar perfusion and reduces the biomechanical impact of lamellar dermoepidermal separation.

SUMMARY

Clinical diagnostic venography allows in vivo visualization of the digital venous system and the effects of venocompression related to foot load and laminitis pathology. Venography has predictive potential and helps the clinician anticipate and treat laminitis tissue damage before it is detectable by plain radiography.

The authors describe the podiatry radiographic technique to correctly perform digital venography and the modifications they have developed. In addition, venography has been applied to investigate the anatomy and physiology of the hydrovolumetric foot-heart pump and its quasistatic biomechanical properties. Using a dynamic PA iron-wood block called the D’arpe-Moreau block, the effects of manipulating the PA on the vascular bed were studied. The results contradict the theory of the foot pump being attributable to frog, cushion, and hoof capsule enlargement during loading and unloading of the foot, which can be valid only in a moving horse with very high values of weight. Instead, they attribute foot-heart pumping to the action of the DDFT modulating flexion and extension movements of the DIP. This produces emptying and filling of the foot vascular bed, enclosed between the hoof capsule and the distal phalanx, even during quasistatic overload. The authors support the existence of a biomechanical safety valve, anatomically constituted by the coronary band that is an interface between the pulvinus coronae and dorsal extensor tendon completed caudally by the collateral ligaments and the ungual cartilages.

The authors provide guidelines for the interpretation of laminitis venograms in the context of laminitis chronology. These are presented as horses that are normal, whereas those with developmental, acute, subacute, or life-long chronic asymptomatic or symptomatic laminitis are differentiated. Frequent venographic monitoring of laminitis helps clinicians understand the sometimes puzzling chronology of the disease process and improves therapeutic outcome.
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