INTRA-ARTICULAR PRESSURE DETERMINATION IN HORSE

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by

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Al “Cavaliere”,
esempio d’amore verso la vita

Alla mia famiglia,
sempre presente

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ABSTRACT

The aim of the present study is to evaluate the intra-articular pressure in horses with distal forelimbs chronic lameness in order to obtain indication about the diagnostic significance of pressure variations. Fifty-six distal interphalangeal (DIP) joint of the forelimbs of 36 horses were investigated by a clinical and radiographic examination and by measuring the pressure with a hand held digital manometer. Forty coffin joints of sound horses were used as a control. The pick pressure was registered for each articulation. The middle pressure measured with the sound horse bearing weight on both limbs was 36.8 mmHg +/-16.0 and 69.6 mmHg +/- 27.3 when the contralateral was lift up. For the diseased horse the middle pressure measured in the two position was 66.5 mmHg +/-7.6 and 132.8 mmHg +/- 43.3 respectively. This result indicates that intra-articular pressure values of the coffin joint are higher in horses with a painful condition of the distal portion of the fore foot.

Anyway, our ranges resulted higher than whose indicated in other reports.

No correlation have been found between articular pressure and kind of radiographic changes of the DIP joint or of the distal sesamoid bone.

Pressure measurement could be considered a useful aid to localize a pathologic condition involving the DIP joint or the navicular bone, but the technique shows some limitation: it seems to be more reliable for diagnosis with both limbs weight bearing because low specificity arises with the contralateral lifted up.

No weight, breed or attitude differences were detected among sound horses. No complications have been reported neither during the examinations nor through the follow-up .

Pressure measurement is an easy, safe, useful and relatively cheap procedure that doesn’t need of the horse hospitalization.

INTRODUCTION

For long time the accurate diagnosis of a disease confined into the hoof represented a big problem for the clinician. Despite many technological advances the difficulties related to the exact localization of pain in the distal portion of the horse foot are not completely solved. Regional anaesthesia of the equine limb is routinely performed to localize the source of pain to an approximating area, nevertheless in the last years the diagnostic value of the intra-articular anaesthesia of the distal interphalangeal joint was revisited because has been shown that it hasn't specificity for the joint but it can eliminate pain related to several pathologies involving the equine foot. For some Authors in these cases measuring the pressure of the DIP joint could be a valid method to identify subjects with synovitis or navicular syndrome and may facilitate the differentiation between disease of the DIP joint or navicular diseased from a pathology involving the surrounding tissues.

The aim of the present study is to evaluate the intra-articular pressure in horses with distal forelimbs lameness in order to obtain indications about the diagnostic significance of pressure variations. Our targets are to contribute to the poor bibliographic data available in scientific literature and to assess the diagnostic usefulness of this technique.

Functional Anatomy of the Foot

The equine foot is an intricately designed structure that accommodates the weight-bearing and propulsive functions of the foot at rest and during locomotion (Parks A, 2006).

The region of the limb below the fetlock is called digit; the horse has only one digit in each limb and it stands on its tips. The horse's hoof is a modified fingernail and it is composed of the wall, sole and frog.

The distal interphalangeal (DIP) joint or coffin joint, is completely enclosed within the hoof and is formed by the distal articular surface of the middle phalanx, the surface of the distal phalanx and the articular surface of the navicular bone. They form three separate articulations: between the middle and distal phalanx, between the middle phalanx and navicular bone and between the distal phalanx and navicular bone. However, the articulation between the distal phalanx and the navicular bone moves very little so that the distal phalanx and the navicular bone essentially function as a single articular surface to articulate with the head of the middle phalanx (Parks A, 2006). The joint capsule attaches to the articular margins of the 3 bones to form both dorsal and palmar pouch, or recesses (Theoret C, 2006). These irregular pockets of joint capsule lie against the dorsal and palmar surface of P2. The dorsal pouch (recessus dorsalis) is a small cavity and the palmar pouch is an extensive cavity that blends with the collateral ligaments and common digital extensor tendon. The palmar pouch is subdivided into a proximal palmar pouch and a small distal palmar pouch extending between the navicular bone and the distal phalanx (Bowker R, 2003). Several small abaxial outpouchings of the coffin joint cavity are in close proximity to the lateral and medial palmar digital nerve.

The navicular bursa lies between the deep face of the deep digital flexor tendon and the deep flexor surface of the navicular bone. Its function is to cushion the flexor tendon as it changes course over the coffin joint but is no longer protected by the aforementioned digital flexor tendon sheath (Theoret C, 2006).

The hoof cartilages (also called lateral, collateral, or ungual cartilages), the digital cushion and the extensive vascular network are important structures of the palmar aspect of the foot that act as a support of the foot and as an energy dissipation mechanism.

Inside the hoof, lateral cartilages, a rhomboid-shape cartilaginous extensions of P3, extend back and up from the inner and outer sides of the third phalanx and lie beneath the coronary venous plexus. The digital cushion is the soft material that can be felt beneath the skin between the two cartilages in the region of the heels. It consist of a meshwork of collagen and elastic fiber bundles that overlies the frog and extends dorsally and attaches to the DDFT and the solar surface of the distal phalanx. Proximally and dorsally the digital cushion fuses with the distal digital annular ligament (Bowker R, 2003).

The vascular network, associated with each lateral cartilages, is a venous microvasculature that forms an hydraulic system hypothesized to be the mechanism for dissipation of the ground impact energies. Those horses with good to excellent hydraulic systems should be more efficient in dissipating the impact energy compared with hoses with feet with less well-developed hydraulic networks (Bowker R, 2003).

During ground impact the frog stay is pushed upward into the digital cushion, the pastern moves downward and the lateral cartilages are forced outward; the impact energy is transmitted to the fluid within the blood vessels. The outward expansion of the cartilages creates a negative pressure within the digital cushion and the venous blood within the vessels of the palmar aspect of the foot is forced into the microvenous vasculaure of the cartilages of the foot. The dissipation of the high frequency energy waves is a consequence of the hydraulic resistance to flow through the microvasculature.

The distal sesamoid bone (navicular bone) is suspended on the palmar surface of the distal interphalangeal joint by its suspensory apparatus; the ligaments that support the navicular bone in its position form a composite structure that consists of several components. The first components are represented by the collateral suspensory ligaments that arise from the distal surface of P1, just dorsal to the collateral ligaments of the pastern joint, and insert on the extremity of the navicular bone, attaching along the abaxial surface of P2. Small branches consist of a ligamentous attachment between the lateral and medial extremities of the navicular bone and P3 (including the hoof cartilage).

The distal sesamoidean impar ligament is a broad and short ligament that separates the coffin joint capsule from the navicular bursa, it extends from the distal border of the navicular bone to the flexor surface of the distal phalanx, across the entire width of the distal interphalangeal joint surface at this level. Between distal border of the navicular bone and the attachment of the distal sesamoidean ligament is a fossa (synovial fossa) containing foramina for blood vessels. Small foramina are present also in the proximal border of the navicular bone.

During extension of the distal interphalangeal joint the middle phalanx contacts the dorsal articular surface of the navicular bone and the navicular bone becomes a weight-bearing structure.

Innervation of the digit

The innervation of the Equine distal forelimb is via the medial and lateral palmar nerve and the medial and lateral palmar metacarpal nerve (Bowker R, 2003).

The medial and lateral palmar digital nerves, that are the distal continuation of the palmar nerves, are located just palmar to their respective artery and vein and lie along the dorsal border of the superficial digital flexor tendon proximal to the pastern joint and along the deep digital flexor tendon distal to the pastern joint (Stashak TS, 2002). Midway down the pastern, the lateral and medial palmar digital nerves form dorsal branches that course superficially along the palmar digital vein, while the primary portion of the nerve continues along the deep digital flexor tondon (Bowker RM, 2007). In some case, an intermediate

STRUCTURE INNERVATED BY THE MEDIAL AND LATERAL PALMAR DIGITAL NERVES

- **Navicular bone**
- **Navicular bursa**
- **Distal straight, oblique and cruciate ligaments (distal sesamoidean ligament)**
- **Distal superficial flexor and deep digital flexor tendons and sheaths**
- **Digital cushion**
- **Corium of the frog**
- **Corium of the sole**
- **Palmar aspect of the phalangeal joints (all of the coffin joint in some cases)**
- **Palmar third and solar aspect of the distal phalanx**

Table 1

From Stashak T.S. Adams' Lameness in the Horses, Fifth Edition, Lippincott Williams & Wilkins, 2002.

branch arises from the dorsal aspect of the palmar digital nerves to innervate the more superficial areas on the dorsum of the digit (Bowker RM, 2007).

Diagnostic analgesia of the digital nerves result in analgesia of most of the foot, including the solar surface (Bowker R, 2003).

Biomechanics of the foot

The distal forelimbs of the horse undergo very high stresses at high speed or during uneven foot bearing and an appreciation of the biomechanics of the foot is helpful to understand lameness and to establish a rational corrective shoeing procedure.

During locomotion the digital (fetlock and interphalangeal) joints undergo a variety of combined movements, especially on uneven surfaces or during turns (Denoix JM and Château H, 2005); experimental studies in vivo and on isolated forelimbs confirms that within interphalangeal joints can be identify three movements during the stance phase: the joints move in sagittal plane (flexion and extension movement), in frontal plane (lateromedial movement) and in transverse plane (rotation and sliding) (Denoix JM and Château H, 2005).

Five different types of forces act on the distal phalanx and on the hoof capsule:

- the force of tension and shear at the foot-laminar junction, this force is the one with important implications in the developmet of laminitis;

- the tension in the deep digital flexor tendon (DDFT), that has implications with navicular disease;
- the tension of the extensor tendon that is a slight force and acts particularly during the swing phase of the stride;
- the body weight applied through the middle phalanx (P2) and ground reaction force (GRF) (Keegan K and Dyson SJ, 2003).

The *stride* is the interval between two consecutive hoof-strike of the same limb, normally at walk the heels impact the ground first followed by the cranial portions of the solar surface of the hoof. The period in which the hoof is in contact with the ground is called the *stance phase of the stride;* this period can be divided in two different phases: the cranial and the caudal phase. The cranial phase starts when the hoof impacts the ground and ends at midstance, when the limb is perpendicular to the ground; this phase is in front of the footprint of the opposite limb, whereas the caudal phase is behind it. The maximal impact force occurs at midstance when the GRF is maximal too, and not at hoof-strike. The rotation of the hoof is called *breakover*, it starts when the heels lift the ground and ends when the toe lift the ground, during this phase compressive force concentrates at the toe and navicular suspensory ligament tension increases (Rooney JR, 1973). The *breakover* is a short period, difficult to measure, but it increases in duration in navicular disease with mild to moderate lameness. When the toe leaves the ground the *flight phase* begins and continues until the hoof impacts the ground at the next impact. The flight phase could be influenced by the hoof conformation like the hoof angle, the toe length and the mass of the hoof. A decreased hoof angle can increase the frequency of toe first landings and the duration of breakover increases with the lengthen of the toe at the walk (Balch O et al, 1991) and at the trot (Balch O et al, 1996). The mass of the hoof has been found to increase the arc of the foot flight and the flexion of the fetlock (Balch O et al, 1996).

The hoof decelerates rapidly after the impact with the ground and a variety of forces in a short period are applied on it; these forces are distributed down through the bones of the leg, the phalanges and particularly the coffin bone inside the hoof capsule, the resultant force applied to the foot reaches the peak magnitude at midstance. At trot the peak force is approximately 1.2 times the animal's body weight and it causes the fetlock to lower toward the ground and stretching the digital flexor tendons and the suspensory ligament (Davies HMS et al, 2007). The impact generates shock waves rich of energy; not all this energy reaches the skeleton but some of it is absorbed in the wall itself and some of it is absorbed during the passage through the tissues between the wall and the coffin bone. In the dorsal half of the hoof, the wall is more rigid for its weight bearing function and more likely to transmit the waves, while in the palmar/plantar half of the hoof all of the soft-tissue structures (the digital cushion, the frog and the lateral cartilages) are extremely important in absorbing the energy of the hoof's impact.

An instantaneous and visible deformation of the hoof occurs when the foot hits the ground, but the changes are too quick to be easily seen. Under the body weight the coffin bone is pushed down and also the wall is dragged down and moves backward, this motion tends to push the quarters into the ground and the reaction force forces the quarters to move outward rather than downward. The heel motion and, in general, the motion of the all part of the wall is influenced by the "corn-like shape of the wall", in response to the downward pull from the coffin bone suspended within it by the laminar junction (Davies HMS et al, 2007). It has long been thought that the outward translation of the heel is due to the compression of the frog or the lowering of second pastern bone, but currently this concept of the rise of the internal pressure within the capsule, as a result of the frog or pastern movement, is changed because the internal pressure decreases as the quarters flare (Krey PR et al, 1971).

The shape of the hoof have been shown influence the mechanical behaviour, particularly changes in shape can modify the distribution of strain and stress inside its tissue, even if the external load does not change (Davies HMS et al, 2007).

An altered hoof orientation, which could result from trimming and shoeing, also influences the intra-articular pressure in the distal interphalangeal (DIP) joint. In one study have been shown that the intra-articular pressure of the DIP joint is higher in legs loaded with heel up, low heel, lateral side up, medial side up imbalance compared to the balanced position (Gadher SJ and Woolley DE, 1987).

Synovium and synovial fluid

Synovium is a vascular connective tissue covering all articular surfaces, excluding articular cartilage and localized areas of bone. It consists of the cells of the synovial intima and a subsynovial stroma but it isn't always homogeneous and in its place in some areas predisposed to trauma, may be found dense connective tissue (Krey PR et al,1971).

The synoviocytes, characterizing the synovial intima, are classified in three cell types:

type A (of macrophage origin) are mainly phagocytic;

type B (fibroblastderived) are the most abundant and synthesize different macromolecules like collagen and hyaluronan (Henderson B and Pettipher ER, 1985; Gadher SJ and Woolley DE, 1987);

type C are intermediate between A and B forms (Ghadially FN and Roy S, 1969; Krey PR et al, 1971; Wilkinson LS et al, 1992). The synoviocytes synthesize different mediators implicated in the pathogenetic events of osteoarthritis, like cytokines (e.g., interleukin-1), eicosanoid (e.g., prostaglandin E_2) and proteinases.

In the subsynovial region there is a blood supply that is essential to produce synovial fluid. It provides a source of nutrition to articular cartilage and facilitates the exchange of nutrients and metabolic wastes of the synovium.

Joint stability is provided by periarticular soft tissues: muscles, tendons, ligaments and joint capsule.

The subchondral bone organization is characterized by an haversian systems oriented parallel to the joint surface rather than parallel to the long axis of the bone (Hvid I, 1988) and the subchondral plate is thinner than the other cortical bones. Besides, the organization of subchondral cancellous bone is different in joints, because of several adaptations to exercise.

The articular cartilage, covering the subchondral plate of bones, is the principal working tissue: it allows to improve movement reducing the friction. It is composed of water, collagen and proteoglycans that are present in respective proportions of 65% to 80%, 10% to 30%, and 5% to 10% of its wet weight (Caron JP, 2003). In most species, less than 2% of its volume is constituted by chondrocytes.

Cartilage is characterized by different zones from the articular surface to the subchondral plate. In the superficial (tangential) zone, cells are elongated and oriented parallel to the joint surface. In the middle (transitional) zone, cells are rounded and randomly distributed. In the deep (radial) zone, cells are distributed in columns oriented perpendicular to the surface. In the calcified zone, cells are combined on crystals of hydroxyapatite. The deep and calcified zones are separated by the tidemark, an irregular line with an unknown function.

Articular cartilage is characterized by an extracellular matrix produced by chondrocytes. Its water content varies with age but may be as high as 80% (Mankin HJ and Thrasher AZ, 1975). Water is in the form of a gel that is responsible of lubrication of articular cartilage and it permits the distribution of compressive load to the cartilage.

Collagen is an essential component of cartilage because it provides structural sustain. Collagen fibrils are oriented in different directions in several zones: they are parallel to the joint surface in the superficial zone, in other zones they are disposed radially. In this tissue two collagen types are present: fibrillar and non-fibrillar. The principal collagen is the type II. It is synthesized by the chondrocytes and it is formed by three amino acid chains organized in a triple helix. It is less soluble, it possesses a higher proportion of hydroxylysine residues and it is more richly glycosylated than type I collagen (Todhunter RJ et al, 1994; Mankin HJ and Brandt KD, 2001). In adult the turnover of the type II collagen is limited, while during growth a considerable remodelling of fibrils occurs. In cartilage there are also minor collagens, the function of which is not clear.

In cartilage there are proteoglycans, that are molecules constituted by proteins and glycosaminoglycans. The most abundant is aggrecan, whose structure is based on the presence of a linear protein that is linked with three globular domains, that are attached to glycosaminoglycan chains of chondroitin sulphate and keratin sulphate. Aggrecan interacts with hyaluronan and this connection is stabilized by a link protein. Equine link protein is similar to that of man. (Dudhia J and Platt D, 1995). Aggrecan is negatively charged because contains carboxyl and sulphate groups; for this reason it is able to bind molecules of water and an hydrated matrix is important for dissipating loads.

Cartilage is formed by numerous non collagenous proteins, such as proteoglycans (lumican, fibromodulin, biglycan, decorin). These proteins interact with other components of matrix and these connections are fundamental for several metabolic processes, for instance the inhibition of fibrillogenesis of type II collagen.

In cartilage there are also some proteins that are neither collagens nor proteoglycans (Heinegard D et al, 1995; Thonar EJ-MA et al, 1999). They have different functions, for example fibronectin is important for the assemblage of matrix's components, that for catabolic processes in conditions of osteoarthritis. Cartilage oligomeric matrix protein (COMP) is essential to regulate the growth of cells of cartilage.

Chondrocytes are important for production of extracellular elements, such as collagens and proteoglycans. They synthesize some proteolytic enzymes useful for degradation of matrix components to assure their turnover. Proteoglycans production by chondrocytes is influenced by several factors, such as load and variations of pressure, attributable to the change of solute content.

In young animals, nutrition of the cartilage is given by subchondral vessels, while in adults articular cartilage doesn’t have vasculature. For this reason chondrocytes are in a state of relative hypoxia with an extracellular pH comprised between 7.1 and 7.2 (Caron JP, 2003). Nutrients are conveyed to the synovial fluid by subsynovial vessels and enter into the matrix of the cartilage by diffusion or facilitated by movements of compression and relaxation of joint. This is the cause for which joint motion is fundamental for cartilage health.

During the motion, lubrication of the cartilage surfaces is very important. There are two systems of lubrication: hydrostatic and boundary (Caron JP, 2003). The first one is valid when the joint is subjected to high loads, while the second system is applied to low loads. Hydrostatic lubrication is assured by water that is liberated from the matrix when cartilage is compressed, while is reabsorbed by the matrix at rest. Boundary lubrication is based on presence of some substances (lubricin and hyaluronan) preventing friction between the two surfaces when joint is subjected to low loads.

Joint motion determines changes of intra-articular volume and pressure, that are respectively minimal and maximal in the extremes of flexion and extension (Schwarz N et al, 1988; Funk DA et al, 1991).

Pathological conditions, like a chronic arthritis, are characterized by a variation of synovial fluid and a reduction of viscosity. The cause of that is a decrease of concentration of hyaluronan, whose determination is not easy and the mucin clot test is not very sensitive. For this reason the quality of hyaluronan is often determined by an inspection of fluid during arthrocentesis. Cytological evaluation of fluid is useful during an articular infection, but it give less information during osteoarthritis because of the scarce quantity of cells and proteins. Total protein concentration is variable in different joints: it becomes higher in larger and more proximal joints, such as the scapulohumeral joint (Caron JP, 2003).

EXAMINATION OF THE EQUINE FOOT

Lameness examination

Lameness is an abnormality of gait that is caused by pain and/or restriction of movement; it could be defined as an indication of a structural or functional disorder in one or more limbs evident while the horse is standing or in movement (Caron J.P, 2003).

For the diagnosis of lameness the examiner needs of a detailed knowledge of anatomy and must be able to differentiate a painful alteration from a “mechanical lameness” (or non-painful alteration) of gait. For that reason, a fair way of working is to take first, with accuracy, the medical history of every horse. A detailed anamnesis should always be the first step of the study, because a complete clinical examination can’t leave out of consideration specific information regarding the duration of lameness, the previous treatments employed, the activity and the attitudes of the horse, the type of shoeing and when was the horse last shod or trimmed, the kind of environment where the horse lives or the kind of management to whom the horse is subjected. A complete clinical examination in combination with an accurate anamnesis is often the most likely entity to achieve a diagnosis also without the opportunity to use collateral and instrumental exams, like the more advanced forms of imaging. In recent years a lot of advances have been made in imaging technologies, this is the reason of the improved knowledges in hoof anatomy and the appearance of “new” diagnosis in antagonism to “old pathologies” (navicular disease vs navicular syndrom, it’s the first example).

The incidence of certain foot problems is often correlated to the breed and the horse activity, and the sport type may be a predilection for some pathologic conditions like the navicular syndrome for polo and jumping horses or foot bruising for quarter horse racing; anyway a correlation between hoof problems and attitudes is not an invariable finding and some pathologies like hoof abscesses, laminitis and thrush are ubiquitous and can affect every horse.

The forelimbs are subject to a much greater concussion than the hindlimbs in according to a different weight distribution between fore and hind legs; the forelimbs carry 60% to 65% of weight and 95% of forelimbs lameness are associated to disease of the distal portion of the limb (Stashak TS, 2002).

Hoof Inspection

The examination procedure should start at distance by the inspection of the feet, in order to evaluate the conformation and to do a comparison of all four feet. Assessment of conformation is an essential part of the clinical examination according to its influences on the horse movements and a relationship exists between a faulty conformation and the development of lameness.

Then a close up inspection with the leg in a weight-bearing position and with the foot lift up is done. The horse should be standing squarely on a flat and regular ground and the clinician should start with the inspection of the feet assessing the size, shape, toe and heel length, contour, the position of each food in relation to each limb. Chronic lameness can lead to disuse atrophy, this condition, visible as a muscle loss that generally takes weeks to months (or few days in non weight-bearing lameness) usually involves the ipsilateral limb, but particularly occurs in extensor muscles as triceps and shoulder muscles. Moreover, horses with chronic lameness have a chronic reduction in weight bearing, generally resulting in a decreased foot size and changes of hoof shape; the smaller foot, ipsilateral to lameness, is more upright and characterized by raised heel or heel bulb contraction with varying degrees of muscle atrophy. Mild disparity in hoof size is a normal finding in some horses, but ideally both forelimbs should have the same size and shape.

Hell bulb of the foot is a region subject to trauma and dermatopathic affections and its examination provides information about foot balance if compared to the other of the same limb. Hoof balance is assessed by evaluating length hell, hoof and pastern angle, hoof wall conformation, coronary bend conformation, shoe position relative to the hoof capsule and distension of distal interphalangeal (DIP) joint capsule. Generally the loss of parallelism between coronary bend and ground surface is a sign of mediolateral imbalance, easily visible as a different medial and lateral wall lengths with the limb bearing weight but also viewing the foot with the limb off the ground.

Swelling is a further cause of asymmetry, it may involve bone and soft tissues and usually is a sign of inflammation; an articular swelling (joint effusion), caused by an increase of joint fluid is a reaction to traumatic event or a degenerative process.

In normal attitude the forelimbs of a standing horse bear the same weight and are opposite each other, whereas an horse with a painful condition on the distal portion of one foreleg tends to point or hold the affected limb ahead of the unaffected limb; with a bilateral forelimb involvement the horse tends to shift the weight from a foot to the other.

The horse is then evaluated at exercise to identify the limb or limbs involved, to do this the horse is observed at walk and trot in a straight line with shoes on (only sometime could be helpful to remove shoes).

What the examiner is looking for is head nodding, gait asymmetry, alteration in height of the foot flight arc, alterations in foot flight, phase of stride, joint flexion angle, foot placement, degree of fetlock extension with weight bearing, action of shoulder muscles (Stashak TS, 2002). Examination should be done from the front, side and rear; the forelimbs lameness is best visualized from the front and side. The foot strike for each foot should be examine in order to verify if the hoof lands flat, heel or toe first, or medial or lateral hoof first; this kind of evaluations are permitted only with the horse walking because it is the one gait sufficiently slow to perceive foot landing abnormalities and fine movements.

The type of surface may influence the lameness, usually the hard surface, providing more concussion of the feet, are preferred because it affords to the examiner a worsening of lameness and the opportunity to visualize the foot placement and also the possibility to listen to the sound of the hoof impact. In fact the unsound foot, bearing less weight, makes less noise than the sound foot.

If the horse is lame on the forelimb, the head will rise when the unsound limb hits the ground and will drop when the weight is placed in the sound foot. Most of lameness aren't visible at walk but becomes visible at trot, because there is only one other limb supporting the weight. The examiner should be able to differentiate a lameness of the homolateral limbs, for example a lameness of fore right from hind right and a lameness of fore left from hind left.

Hoof palpation

After inspection a good way to operate is to perform the palpation of the foot, in a weight bearing position first and with the foot lift up later; the direct digital palpation with the limb elevated is called deep palpation. Different opinions exist about the exact timing of palpation: some Author prefers to complete palpation before the horse is moved because this facilitates localization of the problem; some other prefers to do a complete inspection and to exercise the horse before palpation.

The examiner should palpate the palmar digital vein, the artery, the nerve bundle and should assess the quality and strength of the digital pulse. Inflammatory conditions are the most common causes of changes in pulse characters; an affected foot tends to have a stronger pulse than in other feet. Several foot abnormalities can lead to such increased or elevated digital pulse and most common causes are hoof abscess, brushing, laminitis, hoof avulsion or cracks.

Careful palpation of the coronet from the medial to the lateral hell bulb is significant in detecting heat and pain or a stronger digital pulse, typical finding of a sore side of the foot. Effusion of the distal interphalangeal joint capsule accompanies many abnormalities of the foot, from early synovitis to chronic osteoarthritis; the clinician places one finger lateral to the common digital extensor tendon and gently pushes in on the joint capsule, first laterally an than medially.

With DIP joint effusion pushing on the capsule in one side of the tendon causes elevation of the capsule on the other side (Ross MW, 2003).

With the hoof in a non-weight-bearing position the examination begins by cleaning the solear surface of the hoof in order to remove debris from the sole, the frog, the lateral and medial bars and improve the visualization of this structures. The application of a digital pressure to the sole gives an indication about the sole consistency and sensitivity but more information are taken by the use of a hoof tester; the same digital palpation to the bulbs of the heels gives indication about the presence of swelling, heat and pain.

Hoof tester offers an additional aids to diagnosis, because it allows the examiner to palpate the hoof in order to identify and localize areas of sensitivity; anyway the results of an examination with this instrument must be treated with caution because animals vary greatly in their response to pressure applied to the hoof, for that reason should always begin with moderate pressure to make subjective evaluation of horse answer and only repeatable vigorous reactions considered significant; the equivocal reactions should be ignored so as to obviate to misleading or should be compared to responses in the other feet. The examination starts at the medial or lateral angle of the sole, with one arm of the hoof tester midway between the coronary bend and the bearing surface of the foot, applying pressure every 2-3 cm trying to include each exit point of the shoeing nail with the aim of check the entire surface of the sole. The tester is then positioned diagonally at the medial quarter wall to the lateral middle aspect of the frog and “vice versa” and finally at medial and lateral quarters or on the hoof wall at the heels. With a positive respond at every intermittent hoof pressure follows a reflexive withdrawal. A condition of sensitivity over the central third of the frog could correspond to a navicular pain, but it is helpful to keep in mind that sometimes a significant hoof problem isn’t correlated to a clear positive response to hoof tester. For this reason the use of hoof testers and the interpretation of findings need experience and preparation.

Flexion and extension tests

The attitude to employ flexion tests during a lameness examination is finalized to exacerbate pain especially when the primary lameness is localized in the region being flexed. Their sensitivity is doubtful and it seems that there are more false positive reactions than false negatives; it's incorrect to give clinical relevance to lameness when a false positive reaction can be seen in clinically normal horses and in those with low grade disease; however a positive reaction to distal limb flexion in sound horses could be a predictable sing of future lameness.

Unfortunately a loss of specificity is due to the impossibility to flex only one joint without flex nearby joint or soft tissues.

The lower limb flexion test is the most common flexion test; it isn't specific for the metacarpophalangeal joint (this joint can be flexed separately from the interphalangeal joints) because placing a hand on the toe and forcing the fetlock into a firm flexion also the proximal and the distal interphalangeal joints are flexed. Attention should be done to avoid the unintentional flexion of carpus thus the limb should be held as close up to the floor as possible. Generally a flexion of 1 minute at a force of 100 N is a good choose and has few false positive responses (Verschooten F and Verbeeck J, 1997). As the limb is placed to the ground the horse should be trotted in hand for 15-20 m in a straight line. A positive response to flexion can be observed with any condition of the distal interphalangeal, proximal interphalangeal and metacarpophalangeal joints; navicular bone or bursa; other causes of palmar heel pain; digital flexor tenosynovitis; any soft tissue problem in the palmar pastern region; and lameness associated with the branches of the suspensory ligament (SL) or proximal sesamoid bones (PSBs) (Ross MW, 2003). In reality in horses with navicular disease or osteoarthritis of distal interphalangeal joint the response of flexion test could be largely variable from a marked positivity to an insignificant reaction.

The extension test (*wedge test*) consists of the elevation of the toe on a wedge or wooden board while the contralateral limb is held up by an operator for nearly 60second, after that the horse is trotted in the same way of the flexion examination; this technique elicites a pressure of the deep digital flexor tendon (DDFT) on the navicular bursa, on the flexor surface of the navicular bone and associated ligaments. Exacerbation of lameness may indicate tendonitis of the DDFT or desmitis of the support ligament of navicular bone (Stashak T.S, 2002).

DIAGNOSTIC ANAESTHESIA

The finality of a lameness examination is the localization of the source of pain and although in the last years many technological advances took place, diagnostic analgesia remains one of the main tool for localize pain and for diagnose some foot disease.

The use of diagnostic anaesthesia requires minimal equipment and it is quite cheap but the operator needs of deep anatomical knowledges, basic technical skill and clinical experience. Local analgesia may be accomplished by perineural infiltration (nerve block), direct infiltration of a sensitive area (regional anaesthesia) and intra-articular or intra-bursal injection (intra-synovial anaesthesia).

The aim of the nerve block application is to localize lameness thus it needs to start with the distal portion of the foot progressing proximad whereas direct infiltration and intrasynovial anaesthesia are used to identify the involvement of a specific structure (Carter GK and Hogan PM, 1996; Stashak TS, 2002).

The mechanism of action of all the commonly used local anesthetics consist to block nociceptive nerve conduction by preventing the increase in membrane permeability to sodio ions (Butterworth JF IV and Strichartz GR, 1990).

Lidocaine 2% (Xylocaine) and mepivacaine 2% (Carbocaine) are the local anesthetic agents generally used for regional and intra-articular or intra-bursal analgesia; mepivacaine seems to be less irritating to tissue than lidocain and for this reason it is preferred for intrasynovial injection. These solution are rapidly effective and the foot regularly becomes anesthetetized in 5-10 minutes after perineural administration. The duration of action of lidocain (nearly 30-45min) is lightly shorter than mepivacain (90-120min) after perineural injection.

Distal interphalangeal joint anaesthesia

Unfortunately the use of diagnostic anaesthetic tests to localize pain inside the hoof is not anatomically specific and the only possibility for the clinician is indicating an approximating area as the source of pain rather than a specific anatomic point.

A lot of studies revealed that intra-articular anaesthesia of the distal interphalangeal joint isn't specific only for lameness originating in the distal interphalangeal joint but it can eliminate pain related to several pathologies involving the equine foot.

In one of these studies (Pleasant RS, 1997) lameness was induced in 6 sound horses by injecting either the left or right front navicular bursa with 5 mg of amphotericin-B, the result, 48 hours later, was a significant reduction in lameness after aesthetic was injected into the distal interphalangeal joint.

In another study (Keegan KG et al, 1996) 8 ml of 2% mepivacaine hydrochloride was injected into the dorsal pouch of forelimb DIP joint of 10 adult horses 30 minutes before euthanasia. Synovial tissue from the DIP joint and podotrochlear bursa and bone tissue from the medullary cavity of the distal sesamoid bone were taken from both forelimbs immediately after death. All synovial and bone specimens were analyzed for tissue concentration of mepivacaine and high concentration of the local aesthetic was found in these districts. The conclusion is that mepivacaine hydrochloride deposited into the DIP joint could anesthetize pain arising from navicular bursa and may decrease pain arising from the medullary cavity of the navicular bone.

Furthermore, pain arising from the sole should not be excluded as a cause of lameness when lameness is attenuated by analgesia of the DIP joint since has been shown that lameness induced by creating solar pain can be alleviated with the injection of mepivacain in the joint space (Schumacher J et al, 2000). Therefore a positive response to distal interphalangeal intra-articular analgesia could mean lameness is caused by an articular problem, navicular syndrome or solar pain (Bassage LH and Ross MW, 2003)

The effect of a non sterile injection of the joint could be disastrous thus an accurate scrub with an antiseptic soap and isopropyl alcohol of the area of needle insertion should always be done; also the use of sterile materials like gloves, needles and syringes is obligatory. Clipping the area could be facultative choose because the risk of infection don’t increase without removing the hair (Hague BA et al, 1997). Several approaches for arthrocentesis of the DIP joint have been described, traditionally the dorsal pouch is the more used access.

With the horse bearing weight, the needle is inserted lateral or medial to the long digital extensor tendon, nearly 1.5 cm above the coronary band directed in a distal and axial direction. An alternative approach is at the dorsal midline, through the coronary band with the needle parallel to the bearing surface of the foot or slightly distal from horizontal. A lateral approach have been describe, it may be safer because the limb can be held, but with this technique the navicular bursa or the digital flexor tendon sheath can inadvertently be penetrated (Vazquez de Mercado R, 1998).

RADIOGRAPHIC EXAMINATION OF THE FOOT

Radiography still offer to the clinician the baseline information about the osseous tissue of the foot, but the arrival and the expansion of sophisticated imaging modalities such as Computed Tomography, Scintigraphy and Magnetic resonance imaging revealed that radiography isn't a particularly sensitive indicator of disease.

Established that radiography can't substitute the clinical examination of the patient, is essential to keep in mind that any radiographic finding should be interpreted in context with the clinical history and physical examination findings.

Common causes of chronic foot lameness are palmar foot pain, DIP joint pain and navicular pain and these diagnoses are commonly associated with radiological abnormalities of the DIP joint, the distal phalanx and the navicular bones (Little D and Schramme MC, 2007).

The indispensable projection for the radiological examination of the DIP joint and the distal sesamoid bone are the lateromedial and the dorsoproximal-palmarodistal (Oxpring) oblique views. Additional views include the palaroproximal-palmarodistal oblique (tangential) projection and the lateral/medial dorsoproximal-palmarodistal oblique projections. An accurate preparation of the foot should always precede the X-ray examination and a navicular block (a stable wooden block) is used to support the foot with an angle of the sole with the horizontal of 65 degrees. This angulation determines a superimposition of the navicular bone with the distal half of the middle phalanx.

Radiographic examination of the navicular bone and DIP joint

The expression “navicular” to indicate the distal sesamoid bone, derives from the boat-shape appearance of this bone in the dorsoproximal-palmarodistal radiographic projection. The outline of the navicular bone varies considerably between animals, but controlateral symmetry should be present between both forelimbs.

In Oxpring view the distal border, visible only when it is projected proximally to the DIP, is visualized as two lines: the proximal line represents the articulation between the navicular bone and the third phalanx, the distal line is the distal border of the bone from which the distal sesamoidean impar ligament originates. A groove, indicated as synovial fossa, is situated between the two distal margins; this groove is lined with the synovial membrane of the DIP joint and several invaginations of the synovial membrane arise from the synovial fossa towards the middle of the navicular bone in a proximal direction. Each invagination contains a nutrient artery incoming the navicular bone in a subsynovial location. Various names have been used to indicate these invaginations such as “synovial channels, canales sesamoidales or nutrient foramina" and they appear as oval-shaped lucencies of variable size in the distal border of the navicular bone. Considerable controversy exists over the significance of the size and appearance of the synovial invaginations and their correlation with the clinical situation of the horse or their involvement with a pathologic condition of the DIP joint. The proximal border of the navicular bone also could be observed as two lines in Oxpring view, representing the dorsoproximal and the proximodistal margins; the lateral and medial margins should have a flat and regular outline.

Different opinions are developing about the significance of the navicular scoring systems based on shape, size and location of synovial invaginations. One well-known grading system created by Dik assigns each navicular bone a grade from 0 to 4 (Dik KJ and van den Broek J, 1995) (Tab. 2).

RADIOGRAPHIC FINDINGS OF THE NAVICULAR BONE IN NORMAL AND DISEASED HORSES	
GRADE	**CONDITION**
0	EXCELLENT
1	GOOD
2	FAIR
3	POOR
4	BAD

Tab.2

In another study proposed by de Clercq (de Clercq T et al, 2000) a collection of isolated navicular bones, normal or affected with navicular disease, was examined using dorsopalmar, lateromedial and palmaroproximal-palmarodistal views. A diagnosis of normality or navicular disease was made, first on each view separately and afterwards based on the combination of the 3 view. This study suggests a diagnostic system in which navicular radiologic findings are classified as: important, less important and not important (Tab. 3).

RADIOLOGIC FINDINGS ON THE DORSOPROXIMAL-PALARODISTAL OBLIQUE VIEW OF THE NAVICULAR BONE	
IMPORTANT SIGNS	1) Localized radiolucent area (“cyst”) 2) Extensive new bone formation proximal border, especially when unilateral 3) Irregular trabecular structure 4) Large distal border fragments
LESS IMPORTANT SIGNS	1) Irregular distal border caused by increased or enlarged synovial invaginations 2) Sharply delineated new bone at proximal border 3) Entheseophytes at wings of navicular bone 4) Asymmetric shape of navicular bone

Table 3: Summary of de Clercq analysis (From de Clercq T., Verschooten F., Ysebaert M., A comparison of the palmaroproximal-palmarodistal view of the isolated navicular bone to other views. *Vet Radiol Ultrasound* 2000 Nov-Dec;41(6):525-33).

In lateromedial view the evidence of obliquity of the navicular bone can't allow an accurate evaluation of the bone, thus the beam should always be direct tangential to both heel bulbs. The joint surfaces of the bone articulate with the second and third phalanges and are well visible in this projection; the proximal border should be smooth and free of enthesiophytes or osteophytes; the flexor surface is visualized as two lines, the more palmar representing the outline of the sagittal ridge of the bone and the more dorsal representing the main flexor surface. The synovial invagination of the DIP joint extending proximally from the synovial fossa (and visible as lucent regions) should not be evident in lateromedial view of normal horses.

The diagnosis of osteoarthritis is commonly associated to a thinning of the articular cartilage that can be radiographically appreciated with a narrowing of the joint space; other main findings related to a degenerative joint condition are the presence of the osteophytes at the joint margin, most often seen on the distodorsal and distopalmar surface of the middle phalanx and on the proximal margin of the navicular bone. A joint involvement should be distinguished from a periarticular disease characterized by spur formation away from the articular margin; enthesiophytes on the dorsal surface of P2 inside the joint capsule, or at the insertion of navicular suspensory (collateral) ligaments are not expression of joint disease.

For some Author the synovial invaginations of the DIP joint, radiographically visible as increased radiolucent zones on the distal border of the navicular bone, could be expression of arthrosis of the coffin joint.

INTRA-ARTICULAR PRESSURE IN THE EQUINE DISTAL INTERPHALANGEAL JOINT

The horse's intra-articular pressure determination, by the articular punction, is known in the distal interphalangeal joint and in other joints. Different opinions exist about the diagnostic value of the pressure evaluation in this joint and several Authors tried to find out the clinical relevance and the possibility of application of the procedure (Shött E, 1989; Höppner S, 1993; Hertsch B and Höppner S, 1993; Rupp A, 1993; Pauritsch K et al, 1999).

Variation in intra-articular pressure are described in healthy and diseased joint and increased joint pressure has been implicated in the development of osteoarthritis. The end stage of osteoarthritis is characterized by the damages of the articular cartilage, ostoephytes formation, inflammation, pain and effusion (Lohmander S, 1994). The synovial effusion has been observed in diseased joints of horses and man. The synovial membrane and mainly the elastic collagenous overlying joint capsule constrain the joint synovial space, so an increase in joint fluid volume should result in an increased intra-articular pressure (Viitanen MJ, 2003).

Also a slight increase of intra-articular pressure has been associated to the damage of the articular cartilage and to the release of metalloproteinases; it is difficult to say if the increase in joint pressure actually leads to articular cartilage damage or if the articular cartilage damage and the articular metalloproteinases release lead to increased synovial fluid volume and thus intra-articular pressure (Viitanen MJ, 2003).

The nutrition and the permeability of the articular cartilage is preserved by a continuous joint movement although a condition of synovial effusion with increased volume of fluids and high pressure in the synovial space, decrease the fluids motility and the pump-mechanism at the base of joint physiology. An increased subchondral bone pressure has also be seen in association with an high pressure into the synovial cavity and the repercussion of a reduced blood flow of the bone may contribute to focal areas of necrosis (Kofoed H, 1986). A condition of hypoxia, hypercapnia and acidity may occur in the synovial fluids during joint effusion, with the inhibition of the glucose and all nutrient supply for the articular cartilage. An additionally reduction of synovial fluid’s pH could result from the activation of acidophilic degenerative enzymes within the pericellular matrix leading to a further alteration of matrix arrangement.

Several factors may influence the intra-articular pressure:

- articular capsule and hysteresis: the continuative high pressure inside the joint determines a progressive dilatation of the capsule and as a result the lowering of the pressure
- articular capsule and synovial fluid conductivity: the trans-synovial flow is related to the fluid conductivity and it is regulated by the intra-articular pressure and the macromolecules dimension. At “breaking point” the fluids start to go through the intra-cellular spaces of the synovial membrane and intra-articular pressure rapidly decreases
- the run off phenomenon: this expression means the flow of the synovial fluid from one pouch to another pouch of the joint in order to equilibrate the intra-articular pressure in every area of the joint
- dimension of the joint: obviously the articular shape and the capacity to contain fluid have a big influence on the joint pressure
- blood flow of the synovial membrane: a reduction in the blood flow of the synovial membrane slows down the absorption of liquid; the use of vasodilatory drugs increasing blood flow may amplify the absorption from the joint.

Intra-articular pressure evaluation has be done in metacarpophalangeal joint and the pressure found in healthy, without distention joints was -2.53 mmHg whereas in diseased joints a positive pressure of 37 mmHg was found (Strand E et al, 1995).

In Shött opinion a physiologic coffin joint pressure is below 16 mmHg (Tab.4), but in general is thought that the normal pressure of this joint should be below 20 mmHg when both forelimbs are weight bearing and below 40 mmHg when the controlateral limb is lifted up; increased values are always a pathological feature and are the result of an acute or chronic synovitis (Höppner S, 1993; Hertsch B and Hartmann S, 1996; Pauritsch K et al, 1999).

PRESSURE WITH BOTH FORELIMBS WEIGHT BEARING	**EVALUATIONS**
UNTIL 15 mmHg MORE THAN 15/22 mmHg MORE THAN 38 mmHg	PHYSIOLOGIC DOUBTFUL PATHOLOGIC
BIG INCREASE AND DOUBLING OF PRESSURE VALUES WITH THE CONTROLATERAL LIFT UP	CLINICAL SIGNS OF DISEASE OR PATHOLOGIC FINDINGS IN X-RAY EXAMINATION

Tab. 4: Shött finding (1989) on intra-articular pressure of coffin joint in healty and diseased horse

Höppner, in her study (Höppner S, 1993), pointed out the diagnostic value of the direct intra-articular pressure measurement in the coffin joint for differentiation of the navicular-syndrom. Only horses with chronic lameness were considered

and she measured intra-articular pressure in all the joints; she made anaesthesia in all the articulations with a pressure > of 20mmHg. She found in 57 coffin joints with positive anaesthesia of the DIP joint a middle pressure of 50 mmHg with both leg weight bearing and 98mmHg with the controlateral limb lift up. In the control group of the same study, including 16 DIP joint of horses without signs of lameness, the middle pressure registered was 14mmHg and 22mmHg with respectively both feet on the ground and with the controlateral lift up.
Obviously the position of the leg has repercussion on the intra-articular pressure; also the balance and the orientation of the foot have been showed to influence the DIP joint pressure and the articular contact area; for which an alterate trimming and shoeing could be detrimental for joint physiology. Viitanen (Viitanen MJ et al, 2003) demonstrated that intra-articular pressure in the DIP joint is significantly higher in legs loaded with heel up imbalance compared to the balanced position and the injection of 5ml of contrast into the joint with heel elevation caused a greater increase in DIP pressure, while heel lowering decrease DIP pressure.

Technique of measurement

The intra-articular pressure of the coffin joint of the horse has been evaluated with an easy and safe method based on the punction of the joint. In the original presentation of the technique the use of a digital manometer was described by Schött (1989) comparing several types of barometers; Schött (1989), Höppner (1993) and Rupp (1993) used the Intra-Compartmental Pressure Monitor System by the Stryker company. An alternative instrument, called Merx by Curser company can be used for the same purpose. In 1999 Pauritsch K et al. tested a simple anaeroid manometer instead of a digital manometer for determine the DIP joint pressure and appreciated that the use of the anaeroid manometer is an accurate, practical and inexpensive method for further investigation of lower limb lameness in horses.

A sterile polyethylene catheter or tube is used to connect the needle to the barometer and the joint pressure is transmitted via an air column to the manometer. Technical differences can be documented regarding the length of the catheter and the length and the diameter of the needle used by different Authors (Tab. 5).

AUTHOR	TYPE OF CATHETER	NEEDLE
SCHÖTT (1989)	220 cm Ø$_{int.}$=1mm Ø$_{ext.}$=2mm	1.2 x 40mm
NOWAK et al. (1992)	50 cm	1.1 x 30mm
RUPP (1993)	50 cm	0.9 x 40mm
HÖPPNER (1993)	200 cm	1.2 x 40mm
PAURITSCH et al.(1999)	------	1.2 x 40mm

Tab.5: Technical differences between the various studies

The used of an aseptic technique is always required, after clipping the hair and aseptic skin preparation, the needle is inserted into the dorsal recessus of the DIP joint.

When the needle reach the synovial cavity of the joint the pressure point to the manometer start to increase and the pick pressure is registered. In some paper two measurement are taken, first with the horse standing on both forelimbs and than with the controlateral limb lift up, usually indicated as "*position A*" and "*position B*".

THE COMPARTMENT SYNDROME

A compartment syndrome is a condition in which increased pressure within a limited space compromises the circulation and function of tissues within that space (Matsen FA, 1980).

It is a complication described in human species, usually related to trauma and often involving the muscle tissue because they are surrounded by tight fascial envelopes, but can occur in any part of the body. The acute form can lead to serious, even life-threatening conditions, and emergency decompression of the affected compartments through complete fasciotomie is absolutely indicated to prevent permanent damage. Blunt or penetrating trauma, infection, burns or vascular injury can be the cause of the acute form of the syndrome (Elliott KG and Johnstone AJ, 2003; Tiwari A et al, 2002); swelling of tissues within a compartment decreases the transmural pressure in capillaries and venules, diminishes local blood flow and causes tissue hypoxia, thus ultimately leading to cellular death (van der Elst M and van der Werken Chr, 2000).

Has been theorized that this assumption could be transferred to the pathophysiology of joint disease; the fluids motion between blood and the intra- and extra-cellular space may lead the tissues inside the compartment to an abnormal increase of pressure. The chondrocytes nutrition is based on the nourishment diffusion assured by the continuous changes of pressure during motion in a pump-like system. An high value of pressure inside the joint may decrease the pump system and the capability of flexion and extension of the joint. In degenerative joint disease a pathologic raise of pressure occurs also in the epiphysis of bone involved and the condition can be considered a form of compartment syndrome (Hertsch B and Hartmann S, 1996). With the aid of an angiographic examination, the instillation of growing quantities of contrast material make evident the capsule dilatation, the progressive compression of the digital artery and the ischemic condition in the hoof area (Hertsch B and Hartmann S, 1996).

MATERIAL AND METHOD

Patients

Fifty-six fore distal interphalangeal (DIP) joints of 36 horses have been examined in the Didactic Veterinary Hospital of the Faculty of Veterinary Medicine of the University of Camerino between January of 2006 and December of 2008. The horses were divided in two groups: the first one composed by clinically sound patients and the second one by diseased patients.

The criteria for inclusion in the first group (group A) were:

1) no lameness reported at recent anamnesis;

2) no signs of lameness at walk and trot;

3) negative results at hoof tester application, flexion and extension tests of the axis digitalis.

4) no signs of radiographically evident lesions in the examined area

This group was composed by 20 horses whose both DIP joints of the forelimbs were examined (totally 40 DIP joints studied); the selected patients were characterized by a great variability of age, sex, weight (from a minimum of 430kg to a maximum of 590kg) and attitude. Nine horses came from a breading farm of standardbred horse and were in training during the study, 6 horses were used in a riding school where they played their mild and daily activities, 5 horses came to the hospital during the period of going on the study for several reasons (not involving the locomotors apparatus) and all of them were used occasionally by the owners like pleasure horses.

For the inclusion in the second group the criteria were:

1) history of chronic lameness at forelimbs;

2) positive result to DIP joint anaesthesia.

Sixteen horses with monolateral lameness were included in this group; no horses with bilateral lameness have been tested and only the articulations of the lame leg were considered (totally 16 DIP joint were studied).

All the patients of the study has been monitored for 4-5 days after the evaluations.

Clinical examination

First step of the study was the knowledge of the horse history; for that reason a case sheet was used for every patients to record the anamnestic data.

In order to identify horses with a normal gait and horses with a baseline lameness all the patients were inspected standing and at walk and trot for about 20m in a straight line on a

Fig. 1: Hoof Tester

strong and regular ground.

The hoof tester was applied on both forefeet of all horses. Many types of hoof tester are available, the instrument used for the present study is showed in fig. 1. It was applied from the sole to the wall with the purpose to test the sole sensitivity and the horse react to subtle pressure, avoiding to place the outside jaw of the instrument too close to the coronary band because it may cause a false positive result. The inside jaw was placed to 4/5 site from the heel to the toe on both the lateral and the medial aspects of the foot, afterwards from the middle of the frog to the contralateral hoof wall with the aim to put pressure on the navicular region.

A lower limb flexion test was than applied in all forelimbs of two groups to exacerbate lameness: a hand was placed on the toe forcing the fetlock and both interphalangeal joints into firm flexion. During the procedure the limb was held as close as possible to the ground, providing a flexion of the distal interphalangeal joint, the proximal interphalangeal joint and the metacarpophalangeal joint, but avoiding to get a flexion of the carpus, too. Force used during flexion ranged of 100 to 150 N and it was applied for 1 minute. As the limb was placed to the ground the horse was trotted in hand for 15-20m in a straight line.

The manipulations of the same limbs were than completed with the application of the *wedge test* as following described. With the aid of an operator to hold up the contralateral limb, the toe of the examined foot was elevated on a wooden board for nearly 60second, after that the horses were trotted in the same way of the flexion examination and verified the responses.

Intra-articular pressure measurement in the distal interphalangeal joint

The measurement of the intra-articular pressure in all the 56 joints of the study followed the clinical inspection and the limbs manipulation.

For this purpose the administration of tranquillizers or sedatives to obtain a pharmacologic restriction has been avoided and the application of a twitchnose during the punction of the joint was the only restraint used.

A little area proximal to the coronary band was clipped laterally and medially to the sagittal plane and an aseptic preparation of the skin was obtained by the use of polyvinylpyrrolidone-iodine 10% and etilic alcohol 90°.

The pressure transducer utilized in this study for the DIP joint pressure evaluation was a hand held digital manometer GMH 3160-13, used in human medicine for the intra-muscular pressure determination (Fig.1).

The instrument was connected to one head of a polyethylene catheter (Lecro-Cath, Vygon, L=200cm, Ø=1,0-2,0mm). while the operator, with sterile gloves, attached a 18G needle (1,2x 40mm) to the other head of the catheter and an assistant resetted the pressure transducer to a 0 mmHg.

Fig.1: The digital manometer

Fig.2: Positioning of the horse

With the horse standing on a flat and regular surface and with both forelimbs bearing weight on the same line, the needle was inserted into the dorsal recessus (dorsal pouch) of the DIP joint, abaxial to the common digital extensor tendon, almost 2cm lateral of the sagittal plane and nearly 1.5cm proximal to the coronary band with a disto-axial orientation. When the tip of the needle reached the synovial cavity, the synovial fluid flowed into the catheter raising the pressure values showed by the manometer.

Two values were registered in two different horse positions: the pick pressure measured with the horse bearing weight on both forelimbs (indicated as POSITION A) (Fig. 3) and the pick pressure measured with the contralateral limb lift up (indicate as POSITION B) (Fig. 4).

After the pressure determination a sample of 0.3 ml of synovial fluid was collected in a EDTA tube for the cytological evaluations; the sample was cytocentrifugated (500 rpm 10'), air-fixed, and stained with May Grünwald Giemsa for the cytological evaluation. Later on the needle was withdrawn and the site of punction was covered with a polivinil pirrolidon iodine 10% solution in horses without lameness, in lame horses the catheter were took out and the needle leaved in site for the injection of local anaesthetic solution into the synovial cavity.

Fig. 3: “Position A”, both limbs bearing weight

Fig. 4: **“**Position B”, contralateral limb lifted up

Distal interphalangeal joint anaesthesia

As already said, the distal interphalangeal joint analgesia was performed to the patients belonging to the group B. At the end of pressure determination, before withdrawing the needle, 5-6 ml of mepivacaine 2% were instilled into the synovial pouch, the needle removed and a slight bandage applied on the area of punction. The horse was rested in box and examined 10 minutes later by trotting him in hand for 15-20m in a straight line.

Radiographic examination

The 56 distal interphalangeal joints and the distal sesamoid bones were radiographically investigated by using a portable device Gierth HF 80/15 plus ultra leicht.

Two projections were obtained after removal of the shoes and already described preparation of the foot:

a) lateromedial projection 90°: the foot was elevated from ground level in a weight bearing stance by positioning the bearing surface on a flat block so that the cassette was placed lower than the solar surface of the foot. The beam was directed horizontal and tangential to both heel bulbs, centered

1cm below the coronary band and midway between the most dorsal and the most palmar aspect of the periople;

b) dorsoproximal-palmarodistal oblique (Oxpring) projection: an assistant firmly held the foot by the cannon bone over a navicular block. The wooden block used in this study was 25cm in height and the oblique part of the top of the block that supported the sole made an angle of 65 degree with the horizontal plane. The beam was centered slightly proximal to the coronary band in the midline of the foot and the cassette (with grid) was positioned by the assistant just behind the heel in a vertical position and perpendicular to the x-ray beam

STATISTICAL ANALYSIS

The dates were elaborated by X^2 test with Yates correction when necessary. The significance was fixed for $P < 0.05$.

RESULTS

Clinical Examination

All the patients with a normal gait at walk and trot that had a positive respond to flexion tests or to hoof tester application were excluded from the first group and from the study.

Each patient of the second group had an obvious lameness at walk or trot and a positive answer to the hoof tester application and to the flexion tests; in 8 horses of this group the lameness was difficult to observe at walk in a straight line but it became clearly apparent at trot under all circumstances.

Intra-articular pressure

The mean values and the standard deviations of the pick pressures were assessed in both groups of horses and in both positions (position A and position B).

Tab. 6 shows the DIP joints pressure values measured in the group A. A significant difference of pressure between the right and the left joint was not evident and the middle pressure was 36.8 mmHg +/-16.0 in the position A and 69.6 mmHg +/- 27.3 when the contralateral was lift up.

HORSE	RIGHT WITH BOTH FORELIMBS WEIGHT BEARING (position A) -mmHg-	RIGHT WITH CONTRALATERAL LIFTED UP (position B) -mmHg-	LEFT WITH BOTH FORELIMBS WEIGHT BEARING (position A) -mmHg-	LEFT WITH CONTRALATERAL LIFTED UP (position B) -mmHg-
1°	40	72.4	30*	61
2°	40.2	126.5	32.1	79.1
3°	59.9 *	94.5	33.5	83.4
4°	57.6	131.6	28.1*	103.6
5°	32.8*	59.2	23*	46.4
6°	5.5	41	11.6	54.5
7°	29.1*	33,9	23	29,5
8°	16.8*	25,5	23,5*	25,5
9°	6.9*	42,5	16.9*	36.9
10°	35.5	52	37.3	50.4
11°	60*	90	63*	89.9
12°	32	83	38	78
13°	70.7*	138	46.1*	53.8
14°	26.1*	60	78.9	86
15°	35.0	76	38*	59
16°	40.2	75.3	42	70.5
17°	38.7	82.5	30.5	64
18°	45.5	92.8	39.8	88.5
19°	29.7*	44.5	38*	58.7
20°	43.6	55.6	52.4*	86.5
MEAN VALUE	37.3	73.8	36.3	65.3
ST. DEV	16.8	32.0	15.6	21.5

Tab. 6: GROUP A-Intra-articular pressure values measured in coffin joints
* Joints with synovial fluid analyzed.

A considerable finding was that no correlation has been found between the DIP joint pressure and the weight of the horse (P> 0.05); in addition pressure values didn't result associated to the age, the sex and the horse attitude (P> 0.05).

The same measurements, performed to the group B are reported in Tab. 7.

HORSE	BOTH FORELIMBS WEIGHT BEARING (Position A) -mmHg-	CONTRALATERAL FORELIMB LIFTED UP (Position B) -mmHg-
1°	56.0	108.0
2°	74.7*	214.5
3°	61.6	103.7
4°	67.8	109.8
5°	70.5*	107.8
6°	61.8	104.4
7°	75.2	102.4
8°	65.4	101.7
9°	78.3*	102.8
10°	66.0	191.5
11°	75.8*	103.0
12°	57.6	188.6
13°	54.0	105.0
14°	71.5*	104.7
15°	69.0*	196.0
16°	59.5*	180.6
MEAN VALUE	66.5	132.8
ST. DEV.	7.6	43.3

Tab. 7: GROUP B-Intra-articular pressure values measured in coffin joints
* Joints with synovial fluid analyzed.

Is evident like in these articulations an higher middle pressure was found in comparison to the pressure findings of the group A; the mean value calculated was 66.5 mmHg +/-7.6 with both forelimbs bearing weight and 132.8 mmHg +/-43.3 when the contralateral was lifted up.

In some cases the contamination with blood of the synovial fluid sample prevented an accurate cytological examinations, in other cases the dislocation of the needle from the joint was the cause of the failure of sampling. Therefore, cytological evaluations were performed in 19 DIP joints of the group A in which the result of the analysis was expression of a physiological condition. For the group B the synovial fluid examination was possible only in 7 of 16 articulations and a mild synovitis was diagnosed in each joint considered on the basis of elevation of leucocytes and/or total protein.

At the end of the study no one side effect occurred and no complications has been reported.

Radiographic examination

As already said, all the horses of the group A were free from every kind of radiographic changes.

Five joints of horses of the group B were radiographically characterized by reduced corticomedullary demarcation of the navicular bone and well defined, crescent shape lucent areas on the distal border of the bone (lolly pop lesions); 4 horses had radiographic evidence of osteoarthritis with the presence of periarticular osteophytes on the distodorsal and palmar aspects of the second phalanx and the proximal articular surface of the third phalanx and navicular bone. One horse showed a prominent entheseophyte on the proximolateral navicular border and asymmetry of the medial and lateral aspects of the bone; no one radiographic change was evident in 6 horses of the group B (Tab. 8).

Fig. 5 Proximal navicular entheseophyte

Fig. 6 Evidence of osteoarthritis of the DIP joint

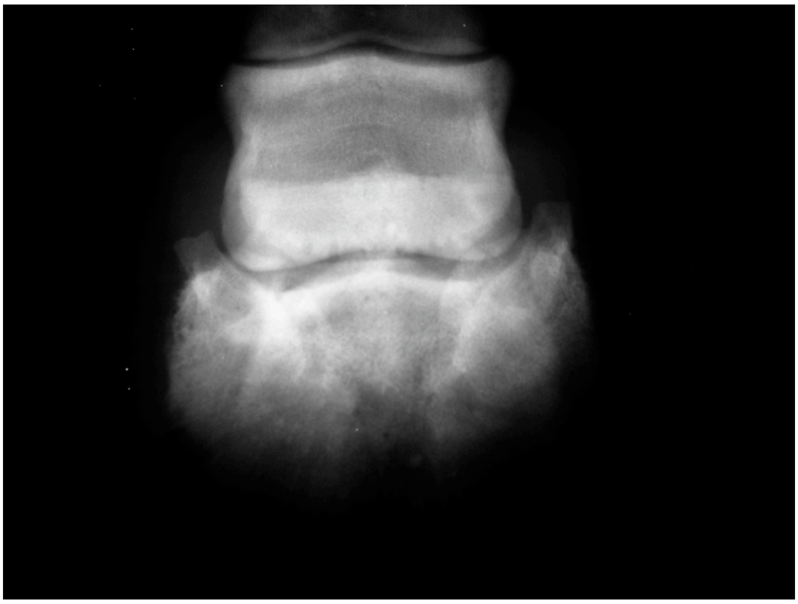


Fig. 7 Crescent shape lucent areas on the distal border of the navicular bone

RADIOGRAPHIC FINDINGS	
5 HORSES	• CRESCENT SHAPE LUCENT AREAS ON THE DISTAL BORDER OF THE NAVICULAR BONE • REDUCED CORTICOMEDULLARY DEMARCATION OF THE NAVICULAR BONE
4 HORSES	• EVIDENCE OF OSTEOARTHRITIS OF THE DIP JOINT
1 HORSE	• PROMINENT ENTHESEOPHYTE ON THE PROXIMOLATERAL NAVICULAR BORDER
6 HORSES	• NO RADIOGRAPHIC CHANGES

Tab. 8: Results of the radiographic examination in the group B.

HORSE	WEIGHT BEARING	CONTRALATERAL	RADIOGRAPHIC FINDINGS	CYTOLOGICAL FINDINGS

	(mmHg)	LIFTED UP (mmHg)		
1°	56.0	108.0	-----	-----
2°	74.7	214.5	DIP JOINT OSTEOARTHRITIS	MILD SYNOVITIS
3°	61.6	103.7	LOLLY POP LESIONS	-----
4°	67.8	109.8	-----	-----
5°	70.5	107.8	LOLLY POP LESIONS	MILD SYNOVITIS
6°	61.8	104.4	-----	-----
7°	75.2	102.4	DIP JOINT OSTEOARTHRITIS	-----
8°	65.4	101.7	-----	-----
9°	78.3	102.8	ENTHESEOPHYTE	MILD SYNOVITIS
10°	66.0	191.5	-----	-----
11°	75.8	103.0	DIP JOINT OSTEOARTHRITIS	MILD SYNOVITIS
12°	57.6	188.6	DIP JOINT OSTEOARTHRITIS	-----
13°	54.0	105.0	LOLLY POP LESIONS	-----
14°	71.5	104.7	LOLLY POP LESIONS	MILD SYNOVITIS
15°	69.0	196.0	-----	MILD SYNOVITIS
16°	59.5	180.6	LOLLY POP LESIONS	MILD SYNOVITIS
MEAN	66.5	132.8	------------	------------
ST. DEV.	7.6	43.3	------------	------------

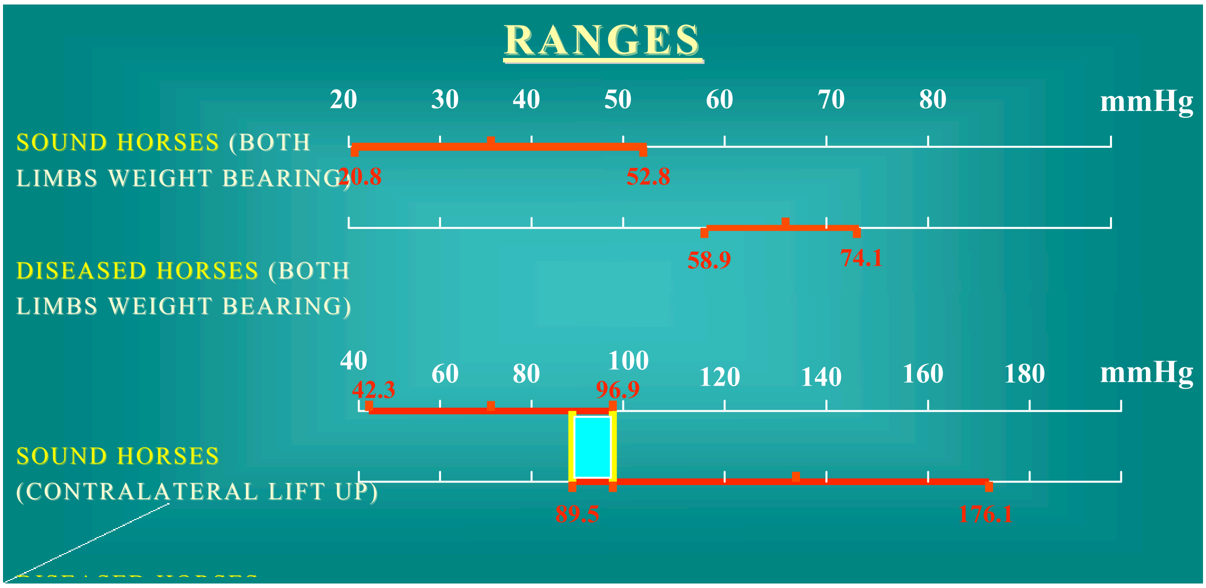
Tab. 9: Relationship between pressure, radiographic and cytological findings in the group B.

DISCUSSION AND CONCLUSION

All unsound horses had an increasing in middle pressure (in both positions) respect to sound horses, resulting in a middle pressure value about the double of no lame horses. Pressure measurement could therefore be considered a useful aid to identify a pathologic condition involving the distal portion of the foot, particularly when the disease is localized in the DIP joint or in the navicular bone. However, the technique shows some limitation.

Making a statistical comparison between the pressure values in sound and diseased horses, in order to determine the grade of significance of the procedure, is possible to confirm the data suspected by the evaluation of the standard deviation that appeared higher when the measurement of pressure was made with a limb lifted up. Comparing the pressure of sound and unsound animals with both limb bearing weight and with the contralateral lifted up can be obtained a significant association (P=0.00001 and P=0.002, respectively). This date indicate that, though both values have statistical significant difference in both positions, accuracy of evaluation is higher when patients stand on two forelimbs.

The explanation of the higher variability of results in position B could be the wide pressure oscillation causing an overlap of the two ranges of values, as testified by high values of standard deviation. This finding is represented in the Graphic A.



Graphic A: Representation of the ranges of pressure in sound and diseased horses in the two positions

In practical terms, both sound and unsound horses had a more wide pressure oscillation (and an higher DS) when one of the limbs were lifted up. This observation could be clearly explained with the decreased balance of the horse and with the increasing of the body movements in some animals. Analysing the same dates in unsound horses, resulted that they have a more wide pressure oscillation then the sound horses when a forelimb was lifted up. This situation could be due to the discomfort of the lame horses when forced to bring the weight on the painful foot, explaining the increasing of the body movements and the modification of the limb position and the weight distribution.

The consequence of these observations is the risk to obtain false positive or false negative results when the pressure is measured with the contralateral limb lifted up. This indicate a low specificity and sensitivity in this position. In conclusion, measurement of intra-articular pressure in the coffin joints seems to be more reliable for diagnosis with both limbs bearing weight, making unnecessary the measurement in two different positions

In our opinion a re-examination of the values of reference indicated in other reports was necessary. Our ranges resulted higher than whose found or used in other scientific study. As we said, according to the study of Shött (1989), a physiologic coffin joint pressure should be lower than 16 mmHg and for other Author pressure of this joint should be below 20 mmHg when both forelimbs are weight bearing and below 40 mmHg when the contralateral limb is lifted up; increased values are always considered a pathological feature and are the result of an acute or chronic synovitis (Höppner S, 1993; Hertsch B and Hartmann S, 1996; Pauritsch K et al, 1999).

To give an explanation of the disparity with our ranges is not easy; a standardization of the procedure should be helpful to avoid each discrepancy of materials and method adopted in different studies (needles, catheters, barometer, etc.); moreover, the poor bibliographic data available in scientific literature reduced our possibility of comparison of the results.

In this study a relationship between the pressure value and the radiographic finding of the DIP joint and the distal sesamoid bone was not found. This is evident in table number 9 were it is shown that an association between pressure value and diagnosis is not a features. This finding highlight as the pressure measurement can not replace other instrumental diagnostic evaluation, such as radiography, in differential diagnosis of foot pain.

Some Authors supported the thesis that pressure evaluation in the coffin joint and in navicular bursa could substitute the diagnostic application of local anaesthesia. In other reports an absolute correspondence between positive results of the DIP joint anaesthesia and increase of pressure was not found, whereby the diagnostic role of the anaesthesia was confirmed as not replaceable. In the present study, despite the exiguity of articulations considered, in each patient with a positive result of the intra-articular block, was registered a pressure higher than the middle value calculated in sound horses.

A condition of palmar foot pain represent a complicate matter for the clinician and the difficulties related to a direct evaluation of the structures contained into the hoof are still present. Nevertheless, in our opinion pressure measurement should be introduced in the schedule for lameness examination. It is an easy, safe and of relatively low-cost procedure that doesn’t need of the horse hospitalization and can also be used during the follow up to verify the progression of the process or the efficacy of the treatment.

Further study should be necessary to better understand witch variables needs to be standardized for improving the repeatability of the measurements. Studies concerning the measurement of pressure in specific pathologic conditions (e.g. navicular bone diseases, DIP joint arthrosis) could improve the knowledge about the possible application in differentiating the site of origin of foot pain.

REFERENCES

- Balch et al: Locomotor effects of hoof angle and medio-lateral balance of horses exercising on a high-speed treadmill: preliminary results. In *Proceedings of the 37th Annual Convenction of the American Association of Equine Practitioners*, 1991.
- Balch O., Clayton H.M., Lanovaz J.L.: Weight- and length- induced changes in limb kinematics in trotting horses. In *Proceedings of the 42nd Annual Convenction of the American Association of Equine Practitioners*, 1996.
- Bassage L.H., Ross M.W., Diagnostic Analgesia–Intra-articular analgesia in the forelimb. In Ross M.W., Dyson S.J., Diagnosis and Management of Lameness in the Horse, Saunders St.Louis, Missouri, pp.93-124, 2003.
- Bowker R.: Functional Anatomy of the Palmar Aspect of the Foot. In Ross M.W., Dyson S.J., Diagnosis and Management of Lameness in the Horse, Saunders St.Louis, Missouri, pp.282-286, 2003.
- Bowker R.M. Innervation of the equine foot: its importance to the horse and to the clinician. In Floyd A. E., Mansmann R.A.: Equine Podiatry, Saunders, St. Louis, Missouri, 2007.
- Butterworth J.F.IV, Strichartz G.R.: Molecular mechanisms of local anesthesia: a review, *Anesthesiology* 72:711, 1990.

- Caron J.P. Osteoarthritis. In Ross M.W., Dyson S.J.: *Diagnosis and Management of lameness in the horse*, Saunders of 63:572-591, 2003.
- Caron J.P., Osteoarthritis – Structure and function of normal joints. In Ross M.W., Dyson S.J., Diagnosis and Management of Lameness in the Horse, Saunders St. Louis, Missouri, pp.572-591, 2003.
- Carter G.K., Hogan P.M. Use of diagnostic nerve blocks in lameness evaluation. Proc Am Assoc Equine Pract 42:26-32, 1996.
- Davies H.M.S., Merritt J.S., Thomason J.J.: Biomechanics of the equine foot. In: Floyd A.E., Mansmann R.A., Equine Podiatry, Saunders, St.Louis, Missouri, pp. 42-56, 2007.
- de Clercq T., Verschooten F., Ysebaert M., A comparison of the palmaroproximal-palmarodistal view of the isolated navicular bone to other views. *Vet Radiol Ultrasound* 2000 Nov-Dec;41(6):525-33.
- Denoix J.M. Château H., Biomechanics and Etiopathogenesis of Equine Distal Limb Injuries. In:9th Congress on Equine Medicine & Surgery in Geneva, 2005.
- Dik KJ., van den Broek J., Role of navicular bone shape in the pathogenesis of navicular disease: a radiological study. *Equine Vet J.* Sep; 27(5):390-3, 1995.
- Dudhia J, Platt D: Complete primary sequence of equine cartilage link protein deduced from complementary DNA, *Am J Vet Res* 56:959, 1995

- Dyhre-Poulsen P., Smedegaard H.H., Roed J., Korsgaard E.: Equine hoof function investigated by pressure transducers inside the hoof and accelerometers mounted on the first phalanx, *Equine Vet J* 26:362-366, 1994.
- Elliott KG, Johnstone AJ Diagnosing acute compartment syndrome. J Bone Joint Surg Br. Jul;85(5):625-32. Review, 2003.
- Funk DA, Noyes FR, Grood Es, et al: Effect of flexion angle on the pressure-volume of the human knee, *Arthroscopy* 7:86, 1991.
- Gadher SJ, Woolley DE: Comparative studies of adherent rheumatoid synovial cells in primary culture: characterisation of the dendritic (stellate) cell, Rheumatol Int 7:13, 1987.
- Ghadially FN, Roy S: *Ultrastructure of synovial joints in health and desease*, London, Butterworth, 1969.
- Hague B.A., Honnas C.M., Simpson R.B., Peloso J.G. Evaluation of skin bacterial flora before and after aseptic preparation of clipped and nonclipped arthrocentesis sites in horses *Vet Surg* 26(2):121-5, 1997.
- Heinegard D, Lorenzo P, Sommarin Y: Articular cartilage matrix proteins. In Kuettner KE, Goldberg VM, editors: *Osteoarthritic disorders*, Rosemont, IL, 1995, American Academy of Orthopaedic Surgeons.
- Henderson B, Pettipher ER: The synovial lining cell: biology and pathobiology, Semin arthritis rheum 15:1, 1985.

- Hertsch B., Hartmann S., Die Gelenksdruckmessung beim Pferd als diagnostische Maßnahme bei der Lahmheitsuntersuchung. Collegium veternarium XXVI, 64-66, 1996.
- Hertsch B., Höppner S., Der diagnostische Wert der Druckmessung im Hufgelenk bei der Lahmheitsdiagnostik und bei der Differenzierung des Podotrochlose-Syndroms. In: Int. Symp. Strahlbeinlahmheiten, Dortmund, Hrsg.: B. Hertsch, FN Verlag, Warendorf, 173-182, 1993.
- Höppner S., Vergleichende klinische Studie über die Hufgelenkanästhesie und die direkte Druckmessung im Hufgelenk als diagnostische Kriterien bei der Differenzierung des Podotrochlose-Syndroms beim Pferd. Hannover, Tierärztl. Hochsch., Dissertation, 1993.
- Hvid I: Mechanical strength of trabecular bone at the knee, *Dan Med Bull* 35:345, 1988.
- Keegan K., Dyson S.J., Clinical Investigation of Foot Pain - General Biomechanics. In Ross M.W., Dyson S.J., Diagnosis and Management of Lameness in the Horse, Saunders St. Louis, Missouri, pp.242-249, 2003.
- Keegan K.G., Wilson D.A., Kreeger J.M., et al: Local distribution of mepivacain after distal interphalangeal joint injection in horses, *Am J Vet Res* 57:422, 1996.
- Kofoed H., Synovitis causes hypoxia and acidity in synovial fluid and subchondral bone. Injury 17:391-394, 1986.

- Krey P.R., Cohen AS, Smith CB, et al: The human fetal synovium: histology, fine structure and changes in organ culture, *Arthritis Rheum* 114:319, 1971.
- Little D., Schramme M.C., Diagnostic Imaging – Radiography and radiology of the foot. In: Floyd A.E., Mansmann R.A., Equine Podiatry, Saunders, St.Louis, Missouri, pp. 141-204, 2007.
- Lohmander S., Biomechanical changes in cartilage in osteoarthritis. In: *Structure and Function of Articular Cartilage,* Eds: V. C. Mow and T. Ratcliffe, CRC Press, Boca Raton, USA, 1994.
- Mankin HJ, Brandt KD: Pathogenesis of osteoarthritis. In Ruddy S, Harris ED, Sledge CB, editors: *Textbook of rheumatology*, ed 6, vol 1, Philadelphia, WB Saunders, 2001.
- Mankin HJ, Thrasher AZ: Water content and binding in normal and osteoarthritic human cartilage, *J Bone Joint Surg Am* 57:76, 1975.
- Matsen FA, III, Winquist RA, Krugmire RB, Jr. Diagnosis and management of compartmental syndromes. J Bone Joint Surg [Am]; 62:286-91, 1980.
- Parks A., Structure and Function of the Equine Digit in Relation to Palmar Foot Pain. In: 52 Annual Convention of the American Association of Equine Practitioners, San Antonio, TX, USA, Lexington KY, 2006.
- Pauritsch K., Rellenrath H., Carola Ballat, Wachbalz M. und Stadler P., Eine alternative Meβmethode des Hufgelenkdruckes im Rahmen der

Lahmheitsdiagnostik beim Pferd, Pferdeheilkunde 15 5(september/october) pp.445-450, 1999.

- Pleasant R.S., Moll H.D., Ley W.B., et al: Intra-articular anesthesia of the distal interphalangeal joint alleviates lameness associated with the navicular bursa in horses, *Vet Surg* 26:137, 1997.
- Rooney J.R.: The lame horse: causes, symptoms and treatment, Hollywood, Calif, Melvin Powers Wilshire Book, 1973.
- Ross M.W. Manipulation. In Ross M.W., Dyson S.J., Diagnosis and Management of Lameness in the Horse, Saunders St.Louis, Missouri, pp.74-81, 2003.
- Ross M.W. Palpation of the forelimb. In Ross M.W., Dyson S.J., Diagnosis and Management of Lameness in the Horse, Saunders St.Louis, Missouri 2003, pp.42-60.
- Rupp A., Erfolgskontrolle der intraartikulären Natriumhyaluronatbehandlung bei Pferden mit positiver tiefer Palmarnervenanästhesie anhand der Hufgelenksdruckmessung mit dem Stryker-Intra-Compartmental-Pressure-Monitor-System. Hannover, Tierärztl. Hochsch., Dissertation, 1993.
- Schött E., Direkte Druckmessung im Hufgelenk bei Pferden-ein Beitrag zur Pathogenese und Therapie von Strahlbein und Hufgelenkerkrankungen. Hannover, Tierärztl. Hochsch., Dissertation, 1989.

- Schumacher J, Steiger R, Schumacher J, de Graves F, Schramme M, Smith R, Coker M., Effects of analgesia of the distal interphalangeal joint or palmar digital nerves on lameness caused by solar pain in horses, *Vet Surg* 29:54, 2000.
- Schwarz N, Leixnering M, Hopf R, et al: Pressure-volume ratio in human cadaver hip joints, *Arch Orthop Trauma Surg* 107:322, 1988.
- Stashak T.S. Examination for Lameness. In Stashak T.S. Adams' Lameness in the Horses, Fifth Edition, Lippincott Williams & Wilkins, pp.113-183, 2002.
- Stashak T.S. Navicular Syndrom (Navicular disease or navicular region pain). In Stashak T.S. Adams' Lameness in the Horses, Fifth Edition, Lippincott Williams & Wilkins, pp.664-680, 2002.
- Strand E., Martin G., Crawford M., Kamerling S., Burba D. and Kearney M. Intra-articular pressure, elastance and range of motion in flexion of the equine metacarpophalangeal joint. *Am. J. vet. Res.* 56, 1362-1371, 1995.
- Theoret C. Anatomy of the Distal Limb and How it Relates to Wounds in this Area. In: NAVC , North American Veterinary Conference Proceedings, 2006.
- Thonar EJ-MA, Masuda K, Manicourt DH, Kuettner KE: Structure and function of normal adult articular cartilage. In register J-Y, Pelletier J-P, Martel-Pelletier J, editors: *Osteoarthritis: clinical and experimental aspects*, Berlin, Springer, 1999.

- Tiwari A, Haq AI, Myint F, Hamilton G.: Acute compartment syndromes. Br J Surg. 89(4):397-412, 2002.
- Todhunter RJ, Wootton JA, Lust G, et al: Structure of equine type I and type II collagen, *Am J Vet Res* 55:425, 1994
- van der Elst M, van der Werken Chr. Fasciotomy for compartment syndrome of the lower leg. Surgical Techniques in Orthopaedics and Traumatology, Paris, Editions Scientifiques et Médicales Elsevier SAS; 55-610-D-10, 2000.
- Vazquez de Mercado R, Stover SM, Taylor KT, Zarucco L, Willits NH. Lateral approach for arthrocentesis of the distal interphalangeal joint in horses. *J Am Vet Med Assoc*. May 1;212(9):1413-8, 1998.
- Verschooten F., Verbeeck J.: Flexion test of the metacarpophalangeal and interphalangeal joints and flexion angle of the metacarpophalangeal joint in sound horses. *Equine Vet J* 29:50, 1997.
- Viitanen M.J., Wilson A.M., Mcguigan H.P., Rogers K.D. and May S.A., Effect of foot balance on the intra-articular pressure in the distal interphalangeal joint *in vitro. Equine Vet. J.* ***35*** *(2) 184-189,* 2003.
- Viitanen M.J., Wilson A.M., McGuigan H.R., Roger K.D., May S.A. Effect of foot balance on the intra-articular pressure in the distal interphalangeal joint in vitro. *Equine Vet J 35 (2):*184-9, 2003.

- Wilkinson LS, Pitsillides AA, Worrall JG, et al: Light microscopic characterization of the fibroblast-like synovial intimal cell (synoviocyte), *Arthritis Rheum* 35:1179, 1992.