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Microanatomy of the intersection of the distal sesamoidean impar ligament and the deep digital flexor tendon: A preliminary report

R. M. Bowker and *Kimberly K. Van Wulfen*

Department of Anatomy, Michigan State University, USA

Summary

The microanatomy of the distal sesamoidean impar ligament (DSIL) indicated that this ligament distally is comprised of multiple dense connective tissue fiber bundles with extensive loose connective septae containing numerous vascular channels and neural networks. In contrast, the deep digital flexor tendon (DDFT) at the level of the distal sesamoid bone and other ligamentous structures consist of broad connective tissue fiber bundles with comparatively little loose connective tissue septae and less of a vascular network. In addition, arterio-venous complexes were observed to be present at the intersection of the DSIL and the DDFT near the attachment to the distal phalanx, which were not present in the DDFT further proximally at the levels of the flexor cortex of the distal sesamoid bone nor in the collateral sesamoidean ligament (ligamenta sesmoidea collateralia; CSL). We hypothesize that these novel arteriovenous complexes may normally aid in hemodynamic perfusion of the tissues through the intersection and the distal sesamoid bone. Furthermore we hypothesize that excessive physical forces impacting upon the intersection of the DSIL and the DDFT during strenuous locomotory behaviors will provide sufficient trauma to initiate inflammatory processes to this soft tissue region. These initial inflammatory processes will result in altered physiological functioning and tissue perfusion of the intersection with its dense innervation and vascular supply leading to other secondary features commonly observed clinically and at necropsy in association with the podotroclosis.

Keywords: podotroclosis, deep digital flexor tendon, impar ligament, horse, coffin joint

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Mikroanatomie des Schnittbereiches von Strahlbein-Hufbeinband und tiefer Beugesehne: ein vorläufiger Bericht

Die Mikroanatomie des Strahlbein-Hufbeinbandes (distal sesamoidean impar ligament, DSIL) zeigte, daß dieses Band im distalen Bereich viele dichte Bindegewebsfaserbündel mit ausgedehnten, lockeren Bindegewebssepten enthält, die zahlreiche Gefäßkanäle und Nervennetze führen. Im Gegensatz dazu bestehen die tiefe Beugesehne (deep digital flexor tendon, DDFT) auf der Höhe des Strahlbeines und andere Bandstrukturen aus ausgedehnten Bindegewebsfaserbündeln mit vergleichsweise wenigen lockeren Bindegewebssepten und einem geringeren Anteil an vaskulärem Netzwerk. Weiterhin wurden im Schnittbereich des Strahlbein-Hufbeinbandes und der tiefen Beugesehne im Bereich ihres Ansatzes am Hufbein arteriovenöse Komplexe gefunden, die weiter proximal in der tiefen Beugesehne, auf Höhe der Sehnengleitfläche des Hufbeines, sowie in den Fesselbein-Strahlbein-Hufbeinbändern (ligamenta sesamoidea collateralia, CSL) nicht zu sehen waren. Wir nehmen an, daß diese neuartigen arteriovenösen Komplexe normalerweise die hämodynamische Perfusion der Gewebe im Schnittbereich und des Strahlbeines unterstützen. Weiterhin vermuten wir, daß exzessive physikalische Kräfte, die während heftiger Bewegung im Schnittbereich des Strahlbein-Hufbeinbandes und der tiefen Beugesehne einwirken, ein ausreichendes Trauma für die Auslösung von entzündlichen Prozessen in dieser Weichteilregion darstellen. Diese anfänglichen, entzündlichen Prozesse bewirken eine Veränderung der physiologischen Funktion und Gewebeperfusion in diesem Schnittbereich mit seiner dichten Innervation und Gefäßversorgung, die zu anderen sekundären Prozessen führt, die man gemeinhin in Verbindung mit Podotrochlose im klinischen Bereich und bei der Autopsie beobachtet.

Schlüsselwörter: Podotrochlose, tiefe Beugesehne, Strahlbein-Hufbeinband, Pferd, Hufgelenk

Introduction

Podotroclosis or navicular syndrome has long been the focus of attention by horsemen, veterinarians and clinical researchers alike as this devastating degenerative disease affects many equine athletes in their prime. Historically, over the years several ideas have been presented as to the possible factors responsible for the syndrome, ranging from genetic and conformational weak nesses susceptible to the excessive concessive forces impacting upon the navicular suspensory apparatus (*Rooney,* 1994; *Stashak*, 1987), to the vascular disorders of ischemia and thrombus formation (*Colles*, 1979; *Rijkenhuizen* et al., 1989b) and compressive insults of the deep digital flexor tendon (DDFT) upon the flexor cortex of the navicular bone (*Hickman,* 1989; *Ostblom* et al., 1989). Frequent observations of flexor cortical thinning and exposure of the subchondral bone, and the presence of adhesions between the DDFT and the distal sesamoid bone at necropsy have fostered the notion that excessive forces of the DDFT acting through the flexor cortex of the distal sesamoid bone serve as a primary causative factor of podotroclosis (*Stashak,* 1987; *Pool* et al, 1989; *Rooney,* 1994). While these and other potential causal factors of podotroclosis have been recently discussed by many scientists and researchers, no one concensus was achieved as to which hypothesis sufficiently explained many of the variations in the reported findings of the underlying pathology associated with podotroclosis (cit. in *Hoppner* and *Dietschmann,* 1994).

Structurally, the distal sesamoid bone (os sesamoideum distale; NB) is supported by the distal sesamoidean impar ligament (liga-

mentum sesamoideum distale impar; DSIL; *N.A.V.*, 1983) between this bone and the distal phalanx, and the collateral sesamoidean ligament (ligamenta sesamoidea collateralia; CSL: *N.A.V.* 1983) attaching the distal sesamoid bone to the proximal phalanx. While the anatomical descriptions of these structures have been reported in detail (*Nickel* et al., 1979; *Sack,* 1991), only scant information is available regarding the microanatomy of these important ligaments suspending the distal sesamoid bone in the equine foot. Such available histological information has focused on descriptions of the blood supply within the DSIL and the CSL to the distal sesamoid bone itself (*Colles* and *Hickman,* 1977; *Fricker* et al., 1982; *Rijkenhuizen* et al., 1989a). The arterial blood supply to the distal sesamoid bone arises from two main sources: (1) a proximal blood source arising from the medial and lateral palmar digital arteries (a. digitalis palmaris communis II and III, respectively), to supply a small, but limited central portion of the proximal part of the distal sesamoid bone; and (2) a distal source supplying approximately 75% of the distal sesamoid bone, that originates from an arterial network within DSIL near the distal border of the distal sesamoid bone. A small contribution of blood flow to the distal sesamoid bone occurs via its abaxial ends (*Rijkenhuizen* et al., 1989a). While small clusterings of arterioles are present within the nutrient foraminae along the distal border of the distal sesamoid bone, controversy exists regarding the roles of these small arterioles and their relationships to podotroclosis (*Hickman*, 1989).
The present preliminary report was undertaken to begin to examine the microanatomy of the DSIL and its components as we believe that understanding the normal anatomy of the DSIL, DDFT and the intersection between these two connective tissue structures will lead to a better appreciation of the pathophysiology of this important clinical problem.

Materials and methods

Fresh forelimbs were obtained from fifteen horses between the ages of five and twenty-two years that were euthanized at the Michigan State University Teaching Hospital. Several breeds were represented, including Standardbreds, Thoroughbreds, Quarter Horses, Appaloosa, Tennesee Walker and grade (mixed). One forelimb from each horse was disarticulated at the metacarpal-phalangeal joint and cut with a bandsaw parasagittally and coronally into several one centimeter slabs and placed into a solution of 3–4% paraformaldehyde solution buffered with 0.1M sodium phosphate. The DSIL and intersection were processed for routine paraffin embedding and staining for hematoloxylin and eosin. Several of the thick sections were placed in normal saline to be processed for gold impregnation. The other forelimb was cut just distal to the carpus, usually within 3–4 minutes of euthanasia, and a small catheter (16 guage needle with P.E. tubing) was inserted into the medial palmar artery in order to infuse the foot initially with 500–700 ml of 0.9% normal saline solution. When the venous effluent was clear, 120–140 ml of a warm (30–35°C), 5% gelatin-India ink solution was infused via the catheter into the upright foot. The proximal metacarpal vessels were then ligated and the exposed end of the limb capped with a latex glove prior to placement of the infused limb in a freezer (minus 20°C). After several days the frozen limb was sectioned parasagittally with a bandsaw and sections were placed in a fixative solution. The DSIL and different regions of the DDFT were then removed, placed in a 25% gelatin solution and allowed to solidify, prior to sectioning them on a freezing microtome at 60–90 microns. The sections were mounted onto gel-coated slides and placed in a humid formalin chamber prior to counterstaining with methylene blue and eosin stains and coverslipping for examination under the microscope.

Results

The distal attachment of DSIL, the DDFT and the connective tissue between them represent an anatomical arrangement that we have defined as the intersection where both the DSIL, DDFT and the intervening connective tissue join together. Examination of the intersection in cross section revealed that the connective tissue fiber bundles were not organized similarly throughout the proximodistal extent of the ligament and DDFT. Rather in the distal half of the ligament near the attachment to the third phalanx, the DSIL consisted of bundles of dense regular connective tissue interspersed with an extensive pattern of vessels and nerve fibers, which were embedded in loose connective tissue septae extending through the dorsoventral extent of the ligament (Fig. 1). This loose connective tissue was continuous with that underlying the synovial lining of the distal interphalangeal (DIP) joint (dorsal to DSIL) and the podotrochlear bursa (ventral to DSIL). Near the intersection at the confluence of DSIL and the DDFT near the distal phalanx, the connective tissue of DSIL formed several ventrally directed synovial and connective tissue strands that passed to the DDFT, forming outpouches between these loose connective septae from the distal synovial surface of the bursal cavity. Proximally near the attachment of DSIL to the distal sesamoid bone the penetrating septae of loose connective tissue were not evident and did not form a large cross sectional surface area of the tissue section as that which was seen in the distal part of DSIL.
In gold stained tissue sections impregnated axons were observed to extend throughout much of the DSIL in a proximodistal direction. These bundles of nerve fibers were present within the loose connective septae penetrating between the separated fiber bundles. The impregnated nerves were seen to extend within the loose connective tissues as well as within the underlying synovial lining of the podotrochlear bursa and the DIP joint.
In the India ink infusion studies of sections from the DSIL, DDFT, and the intersection between DSIL and the DDFT, the vasculature

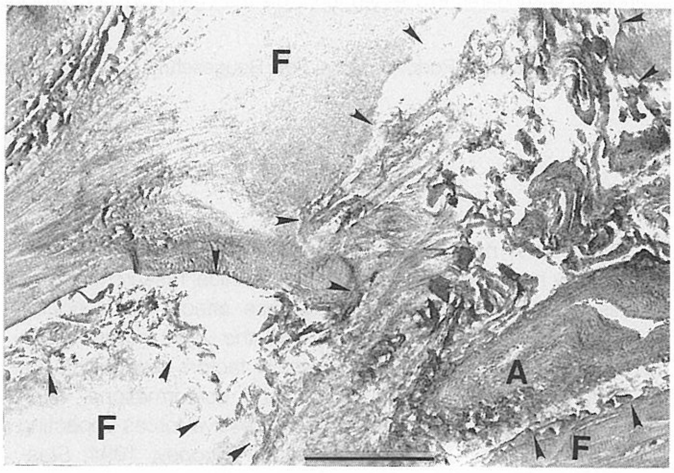

Fig. 1: Photomicrograph of coronal section through DSIL at the intersection. Observe the penetrating septae (between arrowheads) between the connective tissue fibers (F) of DSIL. A: Artery among nerves and small arterioles and venules. Calibration line: 200 microns.

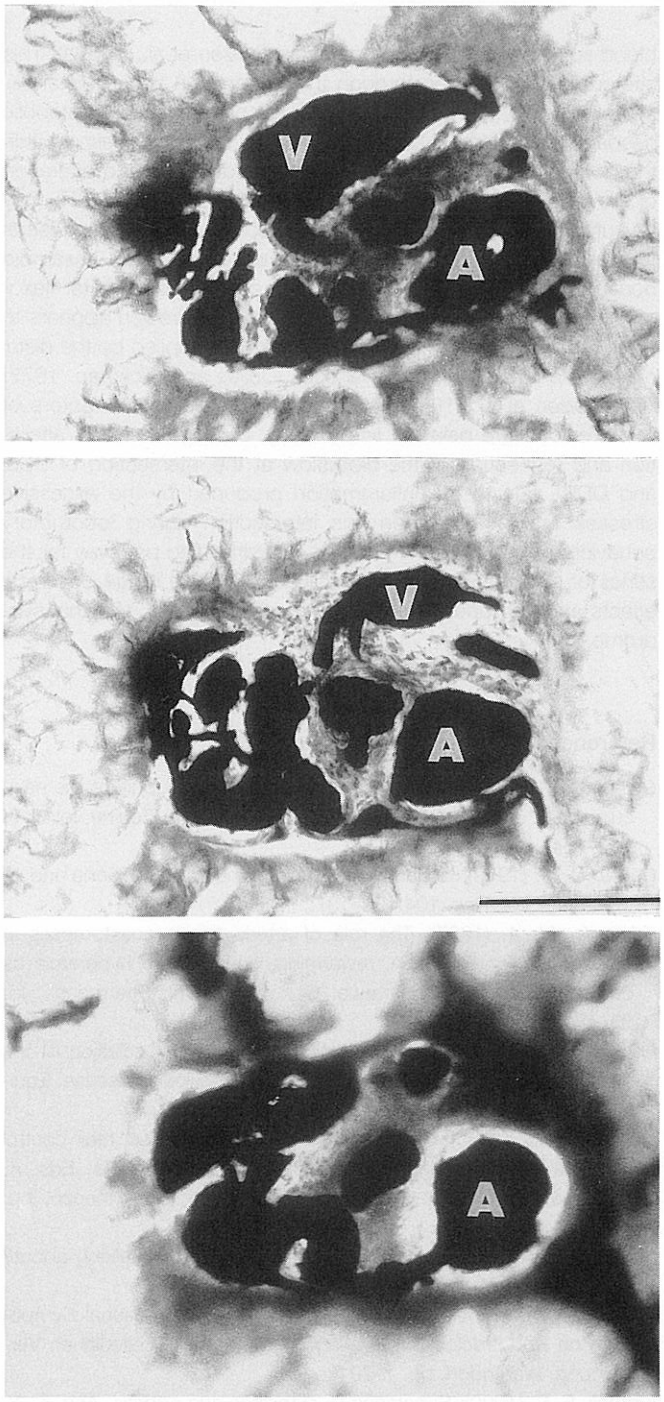

Fig. 2–4: Serial sections showing vessels filled with India ink at intersection of DSIL and DDFT. Observe that all the vessels communicate with one another within this arterio venous complex. A: small artery; V: small vein. Calibration line: 200 microns.

within these structures was easily identified as the small arteries, capillaries and small veins coursing through the connective tissues contained black India ink. In serial sections through DSIL and the DDFT at the intersection, the India ink filled arteries could be seen to give rise to a smaller capillary network that was surrounded by considerable loose connective tissue and epithelial-like cells (Fig. 2–4). The capillary cluster could be followed over several serial sections as they then emptied into a larger dilated vessel (small vein). Fig. 5 illustrates a drawing of several serial sec-

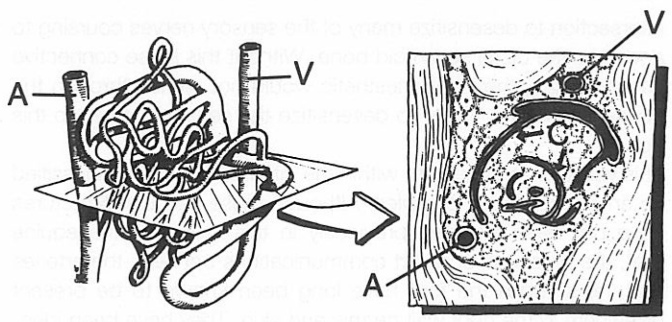

Fig. 5: Reconstruction drawing of arteriovenous complex obtained from several serial sections at intersections. A: artery; V: vein; C: capillary.

tions. This clustering arrangement of the India ink filled vessels was consistent within the intersection, DSIL and dorsal portions of the DDFT in contrast to the absence of the arterial and venous arrangements in the DDFT at the level of the flexor cortex of the distal sesamoid bone and CSL further proximally. At more proximal levels of DDFT, the India ink filled vessels revealed a close juxtapositioning of several very small arteries and small veins or venules (usually two to four vessels), but lacked an elaborate arrangement of the arteries and veins and any tortuous intervening connection of capillaries.

Discussion

This study has demonstrated that the microscopic anatomy of the intersection, i.e., the distal part of DSIL and the DDFT near the attachment to the distal phalanx, contains an extensive array of loose connective tissue penetrating through the ligamentous structures along with vessels and sensory nerves. In contrast, the loose connective tissue arrangement of septae is not present at the proximal attachment to the distal sesamoid bone. In addition, the presence of unique arteriovenous complexes surrounded by loose connective tissue and epithelial-like cells appear to be localized only to this region of the intersection, DSIL and the DDFT.

This microscopic anatomy of the intersection with its abundant sensory nerves and loose connective tissue suggests that this region may have several unique functions, unlike other ligaments and connective tissues within the equine foot. The suspensory apparatus, especially the distal sesamoid bone, has long been viewed functionally to provide a constant angle of insertion of the DDFT in order to prevent any sudden vector changes in acceleration (*Rooney*, 1969). However, the abundant loose connective tissue surrounding the dense fiber bundles of DSIL suggests further that the DSIL and distal sesamoid bone are capable of much movement, not only dorsoventrally, but proximodistally as well. Such movements can be appreciated during dorsiflexion of the DIP joint when the distal sesamoid bone accepts a weight-bearing role of the middle phalanx (unpublished observations). The distal sesamoid bone under these conditions appears to be suspended by the strong CSL attaching to the first phalanx. Also, the abundant sensory nerves suggests that this region may have a role in sensory detection (see below). The abundant loose connective tissue in the distal portion of DSIL with the enclosed sensory nerve fibers also provides a unique anatomical arrangement when local anesthetics are injected into the DIP joint. Such local anesthetic injections into the DIP joint result in the local anesthetic diffusing through the loose connective tissue of the DSIL and intersection to desensitize many of the sensory nerves coursing to and from the distal sesamoid bone. Without this loose connective tissue septae, the local anesthetic would not diffuse through the dense connective tissue to desensitize the sensory nerves to this bone.

This vascular arrangement within the intersection can be classified as an arteriovenous complex. Although these vascular structures have not been reported previously in this region of the equine foot, the presence of direct communications between the arteries and veins within the foot have long been known to be present elsewhere in the hoof wall dermis and skin. They have been identified throughout the dorsal wall of the equine foot previously (*Molyneux* et al., 1994). While the possible functions of these complexes are many, the actions of these vascular structures are not understood completely (*Hales*, 1985; *Edwards,* 1967). One such function appears to be a mechanism of thermoregulation in which during extreme cold, body heat is conserved as the warm blood passes directly from the arterial system into the venous system; thereby completely by-passing the capillary network during perfusion of tissues and reducing external heat loss.

However, this artery and venous arrangement within the distal suspensory apparatus and the DDFT most likely does not have a temperature conservation function due in part to the location of these structures deep within the internal parts of the equine foot, and to the presence of the "epithelial-like" or loose connective tissue surrounding this vascular arrangement. These complexes do not have the same morphology as previously described arteriovenous anastomoses that are present in the dorsal wall. We hypothesize that one possible function of these vascular complexes is sensory or, more specifically, mechanoreceptive in nature, acting to maintain normotensive bloodflow to the distal sesamoid bone. Detection of alterations in vascular and/or tissue pressures within the foot, or in the physical forces acting upon the distal phalanx and the distal sesamoid bone, may serve as the appropriate sensory stimulus during locomotion. Physical forces would include tensile and compressive forces that occur with foot contact with the ground during locomotion and have been shown to act upon the DDFT, DSIL and the intersection (*Leach,* 1990). Such forces are in excess of 1–2 times the animal's weight. At other levels of the DDFT these arteriovenous complexes are lacking and, therefore, the physical forces and the mechanical stimuli would have only minimal or less effect upon the bloodflow through the intersection and the navicular suspensory apparatus in comparison to the potential effects of detection of mechanical stimuli at the intersection, DSIL and distal DDFT.

This intricate vascular and neural network present at the intersection, when damaged, may play an important role during the initial phases of podotroclosis by influencing the bloodflow and tissue perfusion through this region of the foot. Our hypothesis is that the connective tissues of the intersection between the DSIL and the DDFT are stressed, resulting in tearing, or (partial) rupture of the vessels, nerves and connective tissues. One stress may occur via the DDFT by excessive exertional locomotory forces of the animal's weight and flexor muscles, and another stress may occur via the forces acting upon the DSIL during weight bearing of the distal sesamoid bone during dorsiflexion of the DIP joint. This soft tissue injury to the intersection, in turn, produces the initial stages of inflammatory events within the connective tissues (*Kimball*, 1993). The inflammatory changes within DSIL, DDFT and the intersection would then alter the tissue perfusion via the complex vascular arrangement to the DSIL/DDFT and the distal sesamoid bone from this distal route which conveys the majority of the blood supply to these structures (*Rijkenhuizen* et al., 1989a). This altered tissue perfusion through the intersection to the distal sesamoid bone would secondarily alter the nutritional and metabolic needs of the sesamoid bone to produce a bony remodeling within the bone itself (*Pool* et al., 1989). Such a diversion and alteration of the bloodflow within the intersection, DSIL and the DDFT may be sufficient to initiate the cascade of secondary events that leads to the observed pathological findings within the distal sesamoid bone, including the extensive erosion on the centrodistal flexor cortical region of the sesamoid bone. Such an erosion appears to be at the peripheral limits of the vasculature supplied by the distal navicular arteries and their branches (*Colles* and *Hickman,* 1977; *Rijkenhuizen* et al., 1989b). While the possible causal factors of podotroclosis are believed to be many, our hypothesis of alteration and redirection of the bloodflow at the intersection of DSIL and DDFT due to the inflammation produced by the excessive stresses and strains upon this intersection during locomotory behaviors may serve as a focused, but simplified pathway for the series of pathological events that lead to a wide range of clinical effects and necropsy findings commonly observed with this syndrome.

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R. M. Bowker
Kimberly K. Van Wulfen

Department of Anatomy
Michigan State University
East Lansing
MI 48824-1316
U.S.A.